N 62 62982

CASE FILE
COPY

NACA RM L54J22

NACA

RESEARCH MEMORANDUM

A LIMITED ANALYSIS OF BUFFETING EXPERIENCED IN FLIGHT BY A NORTH AMERICAN F-86A-1 AIRPLANE WITH AND WITHOUT LARGE EXTERNAL FUEL TANKS

By Jim Rogers Thompson, Thomas C. O'Bryan,
and Max C. Kurbjun

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

September 2, 1955
Declassified November 2, 1956

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

A LIMITED ANALYSIS OF BUFFETING EXPERIENCED IN FLIGHT BY A NORTH AMERICAN F-86A-1 AIRPLANE WITH AND WITHOUT LARGE EXTERNAL FUEL TANKS

By Jim Rogers Thompson, Thomas C. O'Bryan, and Max C. Kurbjun

SUMMARY

A limited analysis of data collected during buffeting of a North American F-86A-1 airplane with and without large external fuel tanks installed has been performed in order to explore the buffeting characteristics of such configurations. The analysis was made in two parts: first, the effects of the tanks on the general buffeting characteristics of the airplane throughout the investigated range of lift and Mach number, and second, detailed study by electrical and numerical frequency analysis techniques of one run in the low-lift high Mach number region where the buffeting excitation appeared to be concentrated at the tanks.

The region investigated extended to values of lift at which severe buffeting was encountered at altitudes between 24,000 and 33,000 feet. The maximum Mach numbers attained were 1.0 without tanks and 0.88 with tanks installed. The principal quantities measured were the pressure loads on the tank and the motions of the airplane structure.

It was found that two different types of buffeting occurred with the tanks installed. Type I occurred principally below a Mach number of 0.77 and appeared to originate on the wing in the same manner as that experienced by the airplane without tanks; whereas Type II, which occurred principally above 0.77 Mach number and below the boundary for the airplane without tanks, appeared to originate on the tanks. During Type II buffeting oscillating pressures occurred only on the rear part of the tank. The oscillating pressure load measured on a section of the tank near the front of the oscillating region was found to be representative of the entire oscillating load on the tank.

The results presented confirm those of NACA RM L53G31 (which apply to an airplane having an unswept wing without external stores) that

buffeting occurs at the lower natural frequencies of the airplane and that the response of the structure in each mode consists of intermittent bursts and is consistent with that expected if a resonant system of low damping is excited by a random input.

INTRODUCTION

The use of external stowage for fuel and armament has increased greatly with the development of high-powered high-density aircraft configurations having thin surfaces and small frontal areas. This trend of development has resulted in significant gains in potential performance; however, the practical utilization of these performance gains is often limited by the occurrence of buffeting which reduces the effectiveness of the airplane as a gun platform, is disturbing to the pilot, and may threaten the structural integrity of the airplane.

Little information has been published on buffeting characteristics of external-store configurations and as a result designers have been forced to base their designs principally on wind-tunnel drag results and, of course, on experience. Buffeting problems which developed have usually been attacked by cut-and-try methods.

In view of the above it appeared that a study of external-stores buffeting problems was desirable. In order to obtain data on the problem, additional instrumentation was installed in a North American F-86A-1 airplane which was undergoing tank steady-load tests. The external stores were fuel tanks which were large and were known to have an appreciable effect on the buffeting characteristics of the airplane. The subject tank has been replaced in general service by a 120-gallon tank of a modified shape that extremely improved the buffet characteristics of the aircraft with tanks on. It was hoped that the tests would provide data on buffeting in which the excitation was localized at the tank as well as delineate the general characteristics of buffeting of a specific airplane configuration. Measurements were obtained of structural motions throughout the buffeting region of the airplane without the tanks installed and both structural motions and pressures on the tank with the tanks installed.

The results are presented and discussed in two parts: first, the effects of the tanks on the general buffeting characteristics of the airplane, and second, a limited study (principally by means of electrical frequency-analysis techniques described in ref. 1) of the mechanism of the buffeting encountered in the high-speed low-lift region where the buffeting excitation appeared to be concentrated at the tanks.

EQUIPMENT AND MEASUREMENTS

Airplane and external store.- A photograph of the North American F-86A-1 airplane with the external stores installed is presented as figure 1 and a drawing showing details of the store installation is presented as figure 2. Additional details and dimensions of the airplane and store are presented in reference 2 which reports results of measurements of steady loads on the store. The external store used was a 245-gallon auxiliary fuel tank manufactured by North American Aviation, Inc. The shape of the tank is, in general, elliptical and has a fineness ratio of about 5. Small horizontal stabilizing fins are installed at the tail of the tank. The weight of each of the instrumented tanks as flown in the subject tests was 273 pounds, about one-fifth that of the tank containing its rated amount of fuel.

Instrumentation.- The motions of the airplane structure perpendicular to the plane of the wing were measured by means of electrical strain-gage accelerometers (maintained at a constant temperature by a thermostatically controlled heating system) located on major structural members. These measurements were made at eight points on the wing, at two points on each tank, and at three points on the fuselage. Transverse motions were measured at two points, and longitudinal motions were measured at one point on each tank. The locations and sensitive directions of the accelerometers are shown in figure 2. The two accelerometer positions in each tank (referred to hereinafter as "C.G." and "tail") are located on the tank center line 50 and 93 percent, respectively, of the tank length behind the nose of the tank.

The outputs of the accelerometers were recorded on an oscillograph. The combined response of the accelerometer-galvanometer combinations was adjusted to have a frequency response flat within about 5 percent to frequencies of about 20 cps so that the motions thought to be of major interest (the lower principal modes of the complete structure) would not be obscured by engine-excited high-frequency vibration. The variation with frequency of the response ratio of the accelerometer-galvanometer combinations to sinusoidal forcing is presented in figure 3.

The normal component of the air load on the tank and fins at each of the 14 stations shown in figure 4 was measured through use of a system which integrated the pressures at orifices distributed around the circumference of the tank at each station. On the body of the tank, 14 orifices were provided at each station. On the fins from 8 to 16 orifices were provided at each station, depending on the local chord of the fin. At each station the pressures from orifices on the top and on the bottom surfaces of the tank were integrated separately and the difference recorded on standard NACA pressure instruments. Additional information on the operation of the system is presented in reference 2.

Although the pressure integrating system was primarily suited for the measurement of steady loads, the response characteristics of each segment of the system was obtained experimentally by applying an oscillating pressure to the orifices and comparing that pressure with the output of the NACA pressure recorder. The phase and amplitude response of the system at each station was matched with that at the other stations by adjustment of the various tubing lags involved. The effect of altitude on the response characteristics of the system was simulated by repeating the calibration with reduced average pressure in the system. The variation with frequency of the response of the pressure systems for the altitude of interest (about 25,000 feet) is compared with the accelerometer response in figure 3.

Indications of the airflow during some of the test runs were obtained from photographs of tufts located on the upper surface of the left wing and on the inboard side of the right tank. Cameras were mounted in the upper part of the fuselage and in the left tank, respectively, and were operated at about 130 frames per second.

Mach number, normal-force coefficient, and pressure altitude were measured during the test runs through use of standard NACA recording instruments synchronized with the oscillograph by means of a common timing circuit. A calibrated nose-boom airspeed system was provided similiar to that of reference 3. The values of Mach number obtained with the system are believed reliable within about ±0.01.

TESTS AND RESULTS

Ground response measurements.- Inasmuch as previous results (for example, ref. 1) have indicated the importance of structural response characteristics in the study of buffeting, an attempt was made to determine the response of the airplane structure to sinusoidal forcing through use of a single shaker of the rotating unbalance type. The force available from the shaker used was ±8 pounds at 10 cps, ±33 pounds at 20 cps, and ±75 pounds at 30 cps. During these measurements the airplane was fueled to a weight condition representative of that obtained during the flight tests and was supported on the landing gear. The tire pressure was reduced to about one-half the normal value with the result that the natural frequency of the airplane as a whole on the tires was between 1 and 2 cps.

The results are presented in figure 5 as variations with forcing frequency of the response of the airplane structure in g units per pound of force. In figure 5(a) the response at the right wing tip to excitation at the right wing tip is compared for the tanks-on and tanks-off conditions. The first four modes are identified in the figure. Comparison of the

results for the front and rear tip accelerometers showed that a considerable amount of torsion is present with bending in the third and fourth modes.

From figure 5(a) the principal effects of the addition of the tanks are the apparent increase of the frequency of the fourth mode, the suppression of the third mode, and the generally higher level of the response. Similar indications were obtained from comparison of results on the left side of the airplane, although the modal frequencies are slightly different and the accelerations are appreciably different. These differences are believed to result from the fact that single-point forcing does not excite the natural modes of the complex airplane structure in pure form. The results are, however, believed to provide rough indications of the frequency and response characteristics of the structure.

The effect of location of the excitation on the response of the airplane structure is presented in parts (b) and (c) of figure 5. The response at the right wing tip to excitation at the right wing tip is compared with that for excitation at the tail of the right tank in figure 5(b). A similar comparison for the response at the tail of the right tank is presented in figure 5(c).

Response to buffeting excitation.- The flight program consisted of dives and wind up turns in which the pilot attempted to penetrate the buffeting region slowly and smoothly until severe buffeting was reached, maintain constant flight conditions for as long as possible, and recover. This procedure was repeated at several different Mach numbers both with and without tanks installed with the result that reasonably complete coverage was obtained at Mach numbers between 0.5 and the maximum obtainable (0.88 with tanks and 1.0 without tanks). The majority of the maneuvers were performed at altitudes between 24,000 and 33,000 feet.

Typical examples of the records obtained are presented as figure 6. In the opinion of the pilot this example is classified as heavy buffeting, and the corresponding flight conditions are a Mach number of 0.86, airplane normal-force coefficient of 0.14, and pressure altitude of 24,000 feet. The oscillograph record (fig. 6(a)) illustrates the character of the response of the structure. The location and sensitivity of each accelerometer is given on the figure. It is evident from the irregular character of this record that all the accelerometer traces contain components at several different frequencies. The obvious difficulty of interpreting traces of this character provides an illustration of the desirability of separating such records into their components through use of frequency analysis methods.

The pressure record (fig. 6(b)) shows that, for the example presented, oscillations did not occur in the tank pressures ahead of station 6 (see fig. 4) but showed large oscillations at and behind station 6. The character of the records is more irregular than that of the accelerometer records; however, it appears that the oscillating pressure at station 6 is largest and contains the lowest frequency components. At stations further rearward the components of the record appear to be of considerably higher frequency.

Figure 2 shows that parts of the aileron and flap overlap parts of the tank and fins and, therefore, motion of these components might have an effect on the measured pressures. The recorded aileron position (see fig. 6(a)) shows an intermittent oscillation of the aileron with respect to the wing at a frequency of about 35 cps and having a maximum amplitude of about $\pm 0.4^{\circ}$. The flap motion was not recorded directly; however, no motion of the flap with respect to the wing could be detected by careful measurement of the tuft pictures. As the aileron motion could be detected on the tuft pictures by a similar procedure, it is concluded that if flap motion was present it was appreciably smaller than that of the aileron.

DISCUSSION

The buffeting data collected during the flight tests have been analyzed and are discussed in two parts. The first part, discussed under "General Characteristics of Buffeting," is concerned with the occurrence and characteristics of the buffeting experienced throughout the investigated range of flight conditions. The second part, discussed under "Detailed Study of Buffeting," applies the frequency analysis methods presented in reference 1 to what is believed to be a representative part of the data for one run with tanks installed in the high-speed low-lift buffeting region.

General Characteristics of Buffeting

Occurrence of buffeting.- Values of lift coefficient and Mach number at which buffeting started and ended during each of the test runs are presented in figure 7 together with the limits of the explored region. Data for the airplane without tanks are presented in figure 7(a). The boundary faired through the points is compared with a boundary for a similar airplane taken from reference 4. The boundary found in the present investigation is considerably lower than that of the reference probably due to the different criteria of buffeting and different instrumentation used in the two tests. The criterion of buffeting used in the present investigation was the occurrence of definite oscillatory motions of the wing tips exceeding an amplitude of about $\frac{1}{4}g$. This is more stringent

than a similar criterion applied to an accelerometer at the center of gravity, due to the large structural magnification present at the wing tips.

Results for the airplane with tanks installed are presented in figure 7(b). The buffeting criterion used differed from that used for the tanks-off case only in that oscillations of the tank accelerations were considered as well as those at the wing tips. The best fairing of the buffet boundary through the test points appears to consist of two segments intersecting at a Mach number of about 0.78; the first showing a decrease of the airplane normal-force coefficient for buffeting with increase in Mach number and the second part showing an opposite variation. The unusual character of the boundary indicated is believed to be associated with the occurrence of two different types of buffeting. The characteristics of the two types of buffeting (identified on the figure by the shaded regions labeled Type I and Type II) are discussed subsequently. The exact location and shape of the boundary between the two regions is poorly defined because of the limited amount of data; however, its existence is definitely established. For example, during one run at a Mach number near 0.82 the buffeting intensity (estimated on the basis of the average acceleration amplitude) decreased slightly as the normal-force coefficient was increased from 0.2 to 0.4 but abruptly increased severalfold and changed character when a normal-force coefficient of 0.45 was reached. Below a normal-force coefficient of about 0.35, the buffet boundary (shown dashed in figure 7(b)) is poorly determined as most of the runs which entered this region were already in light buffeting when the recorders were turned on.

The limits of the explored region are indicated for the tanks-on and tanks-off cases in figure 7(a) and (b) by the lines at the outer boundaries of the shaded regions. At Mach numbers below about 0.95, these lines correspond to roughly equivalent values of heavy buffeting and correspond to a severity of buffeting which the pilot did not consider it prudent to exceed. These limits appear to diverge as the Mach number is increased above 0.5 and, in the case of the airplane with tanks, restrict the performance of the airplane to a Mach number of about 0.88.

Occurrence of oscillating pressures on tank.- The values of normal-force coefficient and Mach number at which oscillations first occurred and ceased in the pressures on the tank are presented in figure 8. These results are similar to the buffet boundary of the airplane with tanks in that up to a Mach number of about 0.76 a boundary faired through the points decreases slowly and appears to be reasonably well defined whereas above Mach numbers of 0.75 to 0.77 oscillations of pressures occurred at all normal force coefficients investigated. Although there is some evidence for fairing the boundary of pressure oscillations with a sharp break near a Mach number of 0.75 similar to the buffet boundary of figure 7(b) the evidence is much less clear than in the case of the buffet boundary. It should be pointed out that the boundary at normal-force coefficients

below 0.4 (shown dashed in fig. 8) is poorly defined for the reasons given in the preceding section.

Characteristics of buffeting.- The three boundaries discussed in the preceding sections are compared in figure 9. It is immediately apparent from this figure that at Mach numbers below 0.76 the boundary for the airplane with tanks is about 0.09 normal-force coefficient below the boundary for the airplane without tanks and that the boundary of pressure oscillations on the tanks corresponds closely with the boundary for the airplane without tanks. Thus, in the region between the two buffet boundaries the tanks are not a direct source of buffet excitation and the buffeting on the airplane with tanks occurs in the same manner as that of the airplane without tanks. On the basis of previous work it is presumed that the buffeting of the airplane without tanks arises from oscillating forces on the wing associated with the occurrence of a sufficient amount of separated flow. The slightly lower buffet boundary of the airplane with tanks compared to that without tanks is probably due to changes in the flow over the wing due to the presence of the tanks and the resulting effect of these changes on the location or area of separation present or on both the location and area of separation simultaneously.

In the region above a Mach number of about 0.77 the occurrence of oscillating pressures on the tank was concomitant with the occurrence of structural motions. Further, above a Mach number of 0.77 but below the buffet boundary of the clean airplane the tank accelerations were noticeably larger compared to the accelerations of the wing tips than was the case for the buffeting experienced in the region below 0.77. It thus appears that two separate types of buffeting occur. The first type (which occurs below a Mach number of about 0.76 and is referred to in fig. 7(b) as type I) originates on the wing and is similar to that encountered by the airplane without tanks; whereas the second type, which occurs at Mach numbers above about 0.77 (type II, fig. 7(b)), is primarily excited at the tank. This differentiation of type is supported by the tuft pictures. Below a Mach number of 0.76 the tuft pictures showed separated flow occurring on the wing at much lower normal-force coefficients than that at which separation was evident on the tank. Above a Mach number of 0.77, however, the tufts on the tank showed wide fluctuations on the rear part of the tank but tufts on the upper surface of the wing remained steady until normal-force coefficients approaching the boundary of the clean airplane were attained.

Although the mechanism of the transition between the two regions is not completely described by the results presented, there appears to be some correlation of the transition between the two regions with the steady load characteristics of the tanks. Contours of tank steady load coefficient (based on wing plan area) as a function of the airplane normal-force coefficient and Mach number are presented in figure 10, where they

are compared with the buffet boundary for the airplane with tanks taken from figure 7(b). It is evident that over a large region the load on the tank is nearly independent of the airplane normal-force coefficient and Mach number. However, as normal-force coefficients of about 0.45 are exceeded the up load on the tank increases rapidly with increase in normal-force coefficient. As the Mach number is increased above about 0.75 below normal-force coefficients of 0.4, the up load decreases rapidly with increase in Mach number and becomes negative at Mach numbers of the order of 0.80 and normal-force coefficients of the order of 0.10. The region in which the buffeting excitation appears to be concentrated on the tank appears to correlate with the region where the up load on the tank is small. The transition between the type I and type II buffeting regions (the break in the boundary) falls in the region where the contours of constant tank steady load are converging rapidly.

Detailed Study of Buffeting

The material presented in the preceding section provided indications that in the low-lift high-speed buffeting region (above a Mach number of 0.77) the principal source of buffeting excitation was localized at the tank. Because of the inherently simpler nature of the problem for known location of the excitation (compared to that for an unknown distribution of excitation), it appeared that detailed study of the data for this region might yield useful information on the characteristics of and the relations between the excitation and response during buffeting. To this end, a run about 20 seconds long was selected as typical of buffeting encountered in the region and the pressures on the tank and motions of the structure were analyzed with particular reference to the frequency domain by use of numerical and electrical frequency analysis techniques. The techniques used gave results in the form of estimates of the power spectral density and, in the case of the numerical techniques, are described in references 5 and 6. The electrical frequency-analysis techniques used differed from those of reference 1 only in that the results are presented in power-spectral-density form rather than average amplitude form.

The run selected was a diving turn maneuver performed between 27,000 and 23,000 feet pressure altitude during which the Mach number varied between 0.82 and 0.87 and the airplane normal-force coefficient between 0.08 and 0.15. The sample records presented as figure 6 were taken from this run. The analysis is restricted to the normal pressures measured on the right tank and the normal accelerations at the right wing tip and at the tail of the right tank as it is believed that these quantities are most representative of the structural motions experienced during buffeting.

Spectra of pressures at different locations along the tank.- It was noted in the section "Results" that proceeding toward the rear of the tank from the station at which oscillating pressures first occurred the amount

of high frequency oscillation present appeared to increase. In order to investigate this observation, a three-second section of the record (14 to 17 seconds, see fig. 6(b)) was selected and 400 points were read at evenly spaced intervals of 0.0075 second by use of Telereader equipment from each of the pressure traces which showed oscillation. The readings were made at the same time on the traces for each station in order that they could be summed. An IBM Card-Programmed Calculator set up in a 40-point matrix was used to compute power-spectral-density estimates of various combinations of these data. The variation with frequency of the power spectral density of the pressure loading on the tank is presented in figure 11 for station 6 (the first station which showed oscillating pressures), station 7, station 8, the sum of stations 6 through 8, and the sum of stations 6 through 14. The power-spectral-density values (in units of lb^2/cps) refer to the total oscillating load and were obtained by multiplying the pressure at each station times the area it represented (fig. 4) before summing. The results presented have been corrected to account for the response of the pressure measuring system presented in figure 3 and were hanned as described in reference 5.

Examination of figure 11 reveals that the spectra at station 6 and at stations 7 and 8 differ markedly. The spectrum at station 6 shows a high level at low frequencies and secondary peaks at frequencies of about 20 and 27 cps, respectively. The spectrum for station 7 shows a small peak at lower frequencies and a relatively steady value at higher frequencies. The spectrum of station 8 is very low in magnitude and is practically flat. The spectrum of the sum of stations 6 through 8 shows the same general characteristics as the spectrum of station 6 at a slightly higher level, the difference increasing somewhat above about 30 cps. The spectrum of the sum of stations 6 through 14 differs only slightly from that of stations 6 through 8. It therefore appears that station 6, the first point at which oscillations were observed, reproduces the salient features of the total load on the tank and is of only slightly smaller magnitude below about 30 cps. Beyond 30 cps, station 6 becomes increasingly less representative. Thus, it appeared that the load for station 6 could be taken as representative of the oscillating load on the tank in the study of the response of the structure to the oscillating load.

Spectra of tank pressures and structural motions.- Inasmuch as it was shown in the preceding section that the oscillating load at station 6 can be taken as representative of the total oscillating load on the tank, point-by-point addition of pressure traces was not necessary. Therefore, electrical frequency analysis techniques (which are faster and more convenient than the computational methods, but are not in this case suited to point-by-point addition) could be used to obtain spectra of tank loads.

A part of the record of the selected run extending from 5 to 20 seconds (measured from the beginning of the run) was chosen for analysis.

The accelerometer traces for the right wing tip and the tail of the right tank and the pressure at station 6 were transcribed into an electrical signal by means of the manual tracing device described in reference 1 and recorded on magnetic tape. A transcription of each of these tapes was then formed into a loop and played into a tuneable, narrow-band-pass-filter type electrical frequency analyzer. The output was recorded in terms of the mean square of the filter output averaged over the entire length of record. This output, divided by the filter area, provides an estimate of the power spectral density of the measured quantities in terms of units^2/cps. The spectral estimates obtained by the electrical analysis technique are subject to statistical uncertainties and accuracy limitations quite similar to those associated with the numerical technique used in the preceding section. The electrical filter was approximately triangular in shape and had a band width of about 4 cps measured between the half power points. A comparison between spectra obtained by the numerical and electrical techniques and some remarks on the uncertainties involved are presented as an appendix.

The variation with frequency of the estimate of power spectral density for the acceleration at the tail of the tank, the acceleration at the wing tip, and the tank load at station 6 are presented in figure 12. Corrections for the response characteristics of the instruments given in figure 3 have been included. The two acceleration spectra, parts (a) and (b) of figure 12, show marked response peaks for the wing tip near 10 and about 40 cps and for the tank near 9 and 30 cps. Both of the spectra show relatively high levels at frequencies above about 40 cps. Near and above this frequency the spectra may be unreliable for two reasons: first, the response of the accelerometers has dropped to one-quarter of its static response at 40 cps which was the limit of the response calibration of the instruments used (note that the response which enters into the power-spectral-density terms is the square of that shown in fig. 3), and second, the manual tracing process used to transcribe the basic data is considered to be increasingly inadequate as frequencies of 40 cps are exceeded.

The pressure load spectrum (fig. 12(c)) shows a generally decreasing trend with increase in frequency and response peaks are not so prominent as in the acceleration spectra. It should be noted that the response of the pressure system (fig. 3) is even less than that of the accelerometers and the remarks on uncertainty in the preceding paragraph also apply to the pressure. It is of interest to note that the relatively prominent peaks evident in figure 11 at frequencies of 20 and 28 cps are not nearly so prominent on the average spectrum for the entire run presented in figure 12(c) indicating that the occurrence of prominent peaks as in figure 11 is exceptional rather than typical of the record.

Comparison of acceleration spectra with structural response data.- The principal features of the spectrum of acceleration at the wing tip (fig. 12(a)) are the large peak near 40 cps and the much smaller peak

near 10 cps. On the basis of comparison of this spectrum with the structural response results (fig. 5) it is considered that the peaks correspond to the first and fourth modes, respectively. Small bumps in the spectra at 15 and 30 cps are thought to indicate the location of the second and third modes. The differences between the frequencies (7.4 cps and 10 cps for the first mode, 39 cps and possibly 41 cps for the fourth) are of the same order as the estimated uncertainty of the frequency of the spectra measurements, about ±2 cps (see appendix). The possibility of aerodynamic effects on the peak response frequency should not be ignored, however, even though the available information on the subject (reference 1 and similar unpublished results) provides indications that such effects have been small in flight buffeting results. Also, the peak response frequencies shown in figure 5 (other than the first) may be different from those in flight because of the probability that the mode shapes excited from a single point are different from those occurring in flight. The first mode frequency obtained in the ground response measurements is thought to be much more representative than those at higher frequencies; thus, the discrepancy between the two sets of data at the first mode should be more significant than the others (see appendix).

The principal responses in the spectra of the acceleration at the tail of the right tank (fig. 12(b)) are at 9 cps (the first mode) and at 30 cps. The 30 cps peak on the spectra is presumed to be the third mode (although the response peaks shown in fig. 5(c) occur at 22 and 26 cps) on the basis of supplementary ground shaking results which showed that several tank modes related to the third wing bending mode occur between 22 and 32 cps. The amplitude of these modes, which differed principally in the amount of side motion present and phase between the two tanks, appeared to depend on the location and direction of the excitation.

Referring to the ground shaking results (fig 5(b)), it is evident that the response at the wing tip is large in the fourth mode for either location of the excitation, but that in the third mode the tip response is much larger for excitation at the tank. Thus, the large amplitude of the fourth mode during buffeting (fig. 12(a)) is consistent with the ground response results (fig. 5(b)) for either excitation at the wing tip or at the tank; however, the barely visible response at the third mode (compared to that in the fourth) provides an indication that the excitation occurred on the wing tip. The response of the tank in the third mode (fig. 12(b)) appears to be more consistent (see fig. 5(c)) with excitation at the tank than with excitation at the wing tip. It is thus apparent that the indications of the ground response measurements as to the location of the excitation are inconsistent. It is thought that the inconsistency results principally from the inadequacy of single-point forcing for excitation of relatively pure natural modes of the complex structure of the subject airplane. Buffeting is not thought to excite pure natural modes; however, the maximum response should generally occur in these modes.

Effect of flight condition and time on buffeting.- In order to investigate the variation in buffeting experienced during the run and its possible dependence on the flight conditions, the output of the transcribed loop-tuned filter system was recorded (through a small time constant system) in time history form for various filter settings. These time histories, for filter settings which correspond to the center frequencies of the principal modes shown in the spectra of figure 12, are presented in figure 13 for the pressure and the acceleration at the tail of the tank and at the wing tip.

It should be noted that the time histories shown are the actual components of the total record which are passed through the narrow band pass filter and not power-spectral-density or mean-square values as discussed previously. The component time histories are, however, distorted by the time constants of the recorder and of the filter. The overall time constant is of the order of 1/2 second and thus variations which occurred much faster than this rate would not be shown. The gross effect is that the amplitude of the actual component time history is subjected to a running average having an averaging period of about 1/2 second.

It is immediately apparent from examination of figure 13 that the component time histories of all the records show large amplitude variations and appear similar to modulated waves. The character of the records is similar to that shown in reference 1 for a different airplane type and is consistent with that which would be expected from the excitation of a sharply tuned mechanical resonant system excited by a random forcing function. Comparison of the component time histories with the time variations of normal-force coefficient and Mach number during the run (shown in fig. 13(b)) reveal no apparent correlation between bumps in lift coefficient or changes in speed and the bursts evident in the component time histories. Further, there appears to be little if any correlation between the bursts in the pressure time history and the bursts in the tank acceleration even at the frequency of highest acceleration response, about 30 cps (fig. 13(e)).

Further information on the effect of time and flight condition during buffeting was obtained by dividing the electrical transcriptions of each of the 15-second records of pressure and accelerations into five equal parts about 3 seconds long. Each of these 3-second segments of the record was then formed into a loop and its spectrum obtained through use of the electrical frequency analysis equipment. The spectra thus obtained are presented in figure 14. Also included in figure 14 is the spectrum for the entire 15-second length of each record for comparison purposes. Each set of 6 spectra is presented in figure 14 in two groups of 3 each in order that the individual curves may be clearly distinguished.

Examination of the spectra presented in figure 14 reveals that almost all the 3-second spectra agree satisfactorily with the total spectrum in

character. The uncertainty of these spectra is, of course, larger than that of the 15-second spectra of figure 12 because of the shorter sample length. The gross variations evident between the spectra of different sections are, however, somewhat larger than the estimated uncertainties of the spectra. (See appendix.) For example, the tank-tail acceleration spectrum for the time interval 17 to 20 seconds (fig. 14(b)) and the pressure spectra for the intervals 14 to 17 and 17 to 20 seconds (fig. 14(c)) show higher than average levels which are presumably indicative of more severe buffeting experienced near the end of the run.

Comparison of acceleration and load spectra.- The spectrum of the pressure load on the right tank, (fig. 12(c)) shows a relatively continuous character different from those of the accelerations and a level which decreases slowly with increase in frequency. Although the pressure spectrum appears to have small peaks superimposed on the steadily decreasing level near 10, 20, 30, and 40 cps, the acceleration spectrum (and, of course, the related velocity or displacement spectra) has well-defined peaks only near 10 and 32 cps. The pressure spectrum would necessarily be a direct function of the motion spectrum if the pressure resulted solely from the motion. Thus, the different character of the spectra (for example, the appreciable pressures near 20 cps where the motion is small) indicates that the pressures due to the motion of the tank are small compared to the total pressures on the tank which presumably result from the character of the separated flow. Further evidence of the apparent independence of the pressure from the motion may be obtained from the time histories of pressure and motion in figure 13. It is apparent from examination of these time histories that there is no direct correlation between the bursts in the filtered components of pressure and motion such as might be expected if the pressure resulted from the motion.

Inasmuch as the pressures do not appear to result from the motion, it would be of interest to determine whether the motions result directly from the pressures presented. The pressures on the left tank, although they might be expected to have spectra similar to those presented for the right tank, would be expected to be independently random in time. Also, the excitation on both tanks (and elsewhere) would be expected to influence the motion of each tank. Thus, the results presented, although they provide a definite indication that the effect of the motion of the tank on the pressures is small, do not provide a definite indication that the motion of the tank results only from the normal pressures presented.

CONCLUDING REMARKS

A limited analysis of data collected during buffeting of a North American F-86A-1 airplane with and without large external fuel tanks installed has been performed in order to explore the buffeting characteristics of such configurations. The region investigated extended to values of lift at which severe buffeting was encountered at altitudes between 24,000 and 33,000 feet. The maximum Mach numbers obtained were 1.0 without tanks and 0.88 with tanks installed. The principal quantities measured were the pressure loads on the tanks and the motions of the airplane structure.

Below a Mach number of about 0.76 the effect of the tanks was to lower the buffet boundary by about 0.09 normal-force coefficient. Above this Mach number buffeting was encountered at all values of normal-force coefficient investigated. The severity of buffeting encountered with tanks installed limited the performance of the airplane to Mach numbers below 0.88.

Two reasonably distinct and different types of buffeting were observed with the tanks installed. Type I, which occurred principally at Mach numbers below 0.77, appeared to originate on the wing (as in buffeting experienced by the airplane without tanks) and was not accompanied by oscillating pressures or unsteady flow on the tanks until after the boundary of the airplane without tanks was penetrated. Type II, which occurred principally above a Mach number of 0.77 and below the boundary of the airplane without tanks, appeared to originate at the tank in that oscillating pressures and unsteady flow were present on the tanks but tufts on the wing were steady. Transition between the two types of buffeting occurred in a region where the contours of constant tank steady normal load are converging rapidly.

Detail study by frequency analysis techniques of a run typical of type II buffeting confirmed the results of RM L53G31 (for an airplane having an unswept wing without external stores) that buffeting occurs at the lower natural frequencies of the structure and that the response of the structure in each mode consists of intermittent bursts and is consistent with that expected if a resonant system of low damping is excited by a random input.

Oscillating pressures were found to occur only on the rear part of the tank. The oscillating load measured on a section of the tank near the front of the oscillating pressure region was found to be representative of the entire oscillating load on the tank up to a frequency of 50 cycles per second. Comparison of spectra of tank pressure load and tank motion (and of detail time histories of load and motion) showed little correlation providing an indication that the oscillating pressures resulted principally from the presence of separated flow rather

than as a secondary effect of the motion of the tank. Because of the limited nature of the measurements and analysis, the apparent independence of the pressure load from the motion should be considered an indication rather than a definite conclusion.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 13, 1954.

APPENDIX

COMPARISON OF SPECTRA OBTAINED BY ELECTRICAL AND NUMERICAL TECHNIQUES

In order to provide an indication of the consistency of the two different spectral techniques, the pressure spectrum for station 6 (obtained by use of the numerical techniques and which was presented in fig. 11) is compared in figure 15(a) with two spectra obtained by electrical techniques from two independent transcriptions of the basic time history for the same time period. A similar comparison is presented in figure 15(b) for the spectrum of the acceleration at the tail of the right tank. It is apparent from this figure that the spectra obtained by the different methods from the same data are generally consistent both in character and in level. The estimated uncertainty of the spectra obtained by numerical methods estimated by the method of reference 5 is of the same order as that estimated for the spectra obtained by electrical means.

The difference between the spectra presented in figure 15 which were obtained by electrical methods from two different transcriptions from the same basic record exceeds the specified uncertainty of the equipment (about ±10 percent in power spectral density, 1 cps in frequency) only below about 10 cps in figure 15(a). This discrepancy is of the type which could result from a tape splice having poor electrical characteristics.

A discrepancy of about 2 cps in frequency is evident between results of the two methods at the response peak near 30 cps in figure 15(b). The estimated frequency uncertainty of both the computational method and the electrical equipment is about ±1 cps; however, due to the difficulty of maintaining the speed ratios at the desired value during the several steps of the transcription process, the absolute frequency uncertainty of the electrical data is increased to about ±2 cps. A further source of frequency error is the tendency of the filter reference to drift during the determination. The frequency scale of the spectra presented herein was corrected so that a calibrated signal of known frequency (which was checked after recording each spectrum) appeared at the correct place on the frequency scale. Application of this correction improved the agreement between the several electrical spectra considerably; however, the frequency scale of the data still appears to be slightly high (i.e., the first wing bending response peak appearing at 9 or 10 cps, whereas on the basis of the ground response measurements, it might be expected to appear at about 7.5 cps).

REFERENCES

1. Yeates, John E., Jr. and Thompson, Jim Rogers: A Preliminary Study by Means of Electrical Frequency-Analysis Techniques of the Response of an Airplane Structure During Buffeting. NACA RM L53G31, 1953.

2. O'Bryan, Thomas C.: Flight Measurement of Aerodynamic Loads and Moments on an External Store Mounted Under the Wing of a Swept-Wing Fighter-Type Airplane. NACA RM L53G22, 1953.

3. Thompson, Jim Rogers, Bray, Richard S., and Cooper, George E.: Flight Calibration of Four Airspeed Systems on a Swept-Wing Airplane at Mach Numbers up to 1.04 by the NACA Radar-Phototheodolite Method. NACA RM A50H24, 1950.

4. Rolls, L. Stewart, and Matteson, Frederick H.: Wing Load Distribution on a Swept-Wing Airplane in Flight at Mach Numbers up to 1.11 and Comparison With Theory. NACA RM A52A31, 1952.

5. Tukey, John W.: The Sampling Theory of Power Spectrum Estimates. Symposium on Application of Autocorrelation Analysis to Physical Problems (Woods Hole, Mass.), June 13-14, 1949, pp. 47-67. (Sponsored by ONR, Dept. Navy.)

6. Rice, S. O.: Mathematical Analysis of Random Noise. Pts. I and II. Bell Syst. Tech. Jour., vol. XXIII, no. 3, July 1944, pp. 282-332; Pts. III and IV, vol. XXIV, no. 1, Jan. 1945, pp. 46-156.

L-78464

Figure 1.- Photograph of North American F-86A-1 airplane with 245-gallon external fuel tanks installed.

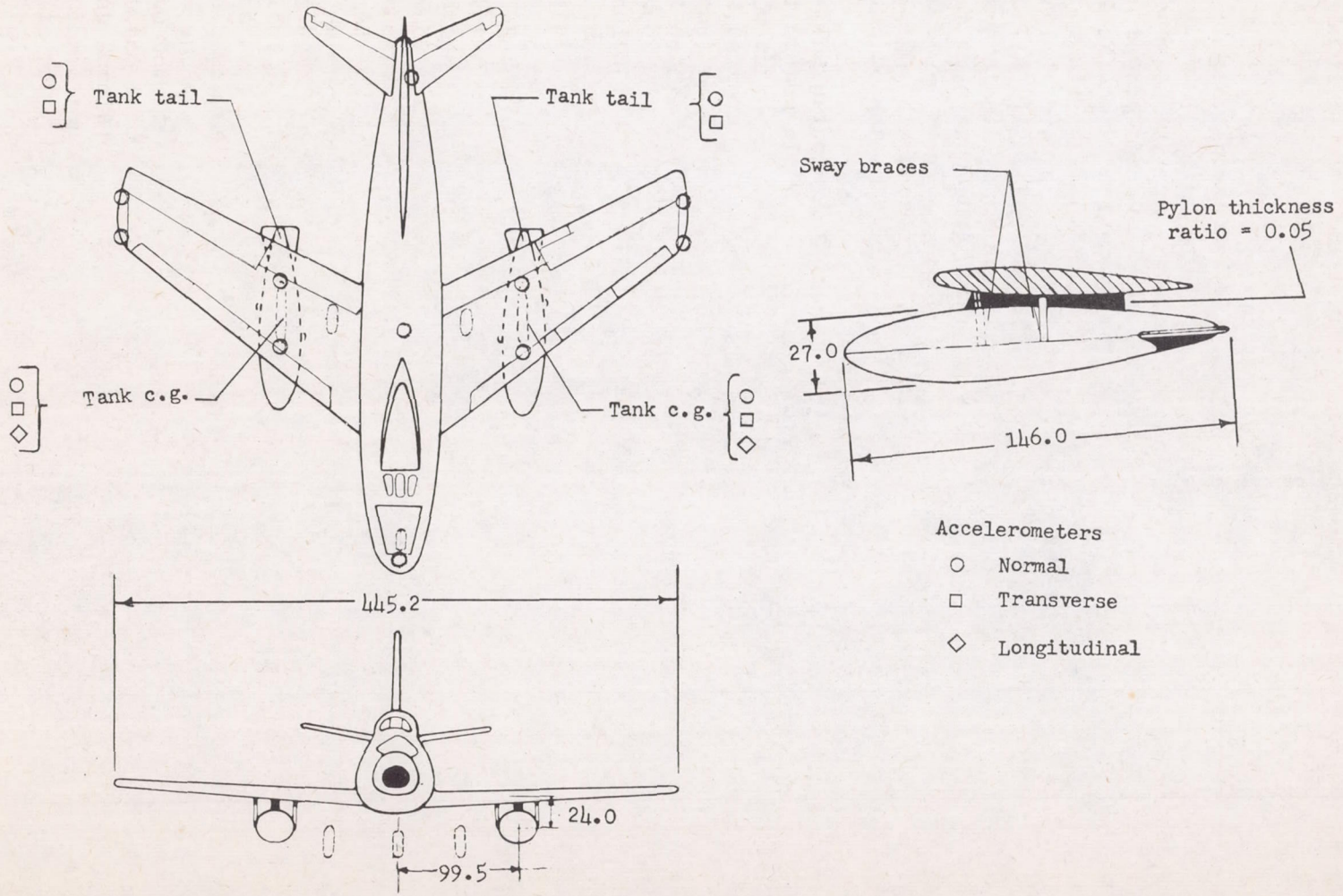


Figure 2.- Drawing of North American F-86A-1 airplane showing details of external fuel-tank installation and location of accelerometers. All dimensions are in inches.

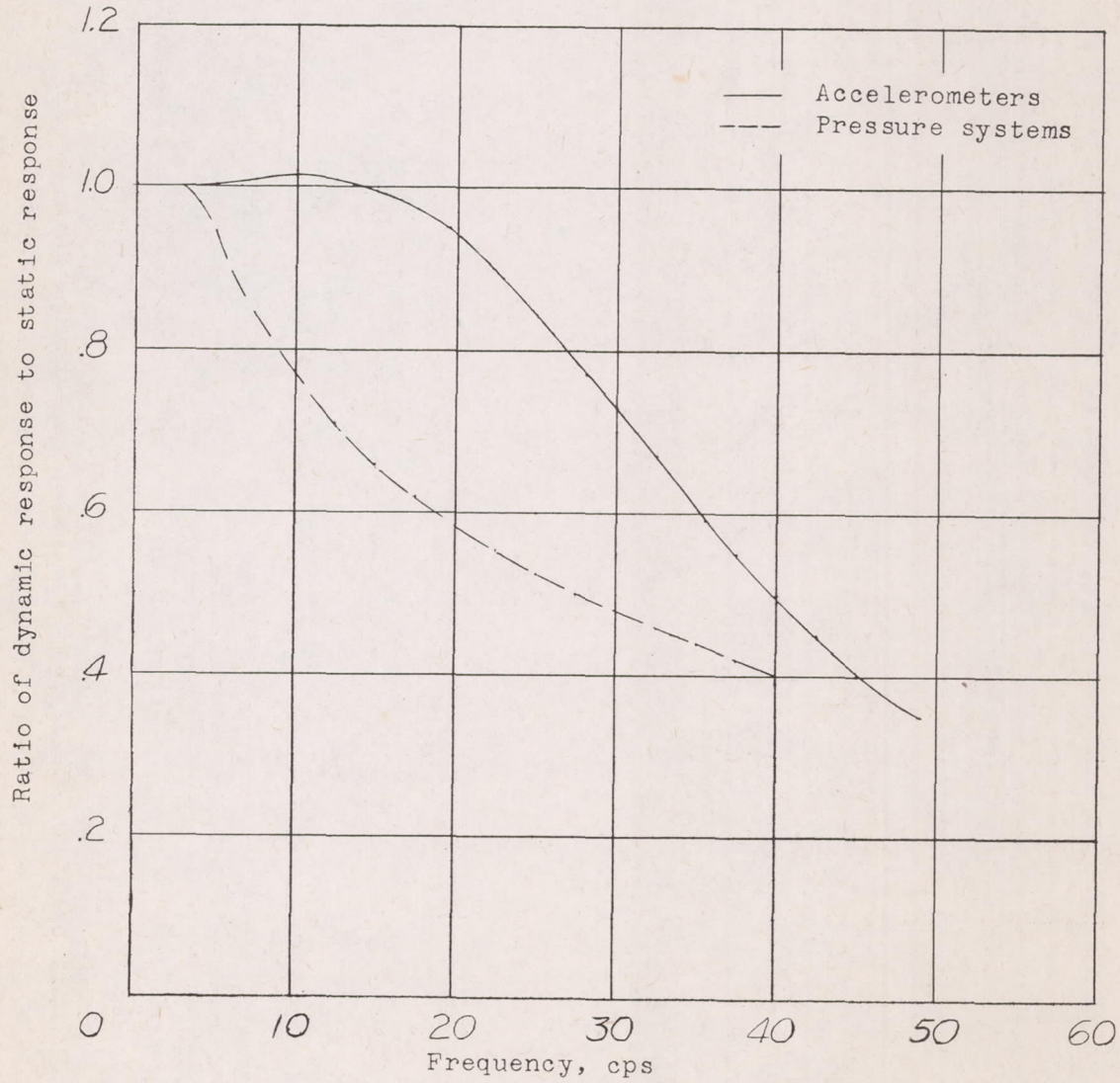
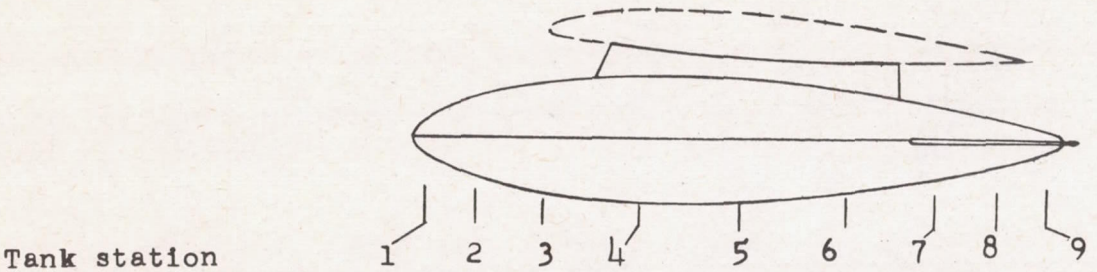


Figure 3.- Variation with frequency of the ratio of dynamic response to static response for the measuring systems used.



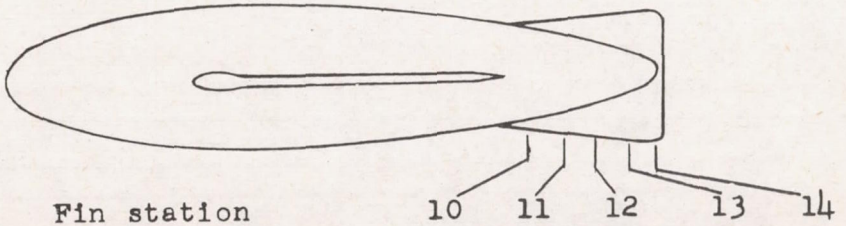
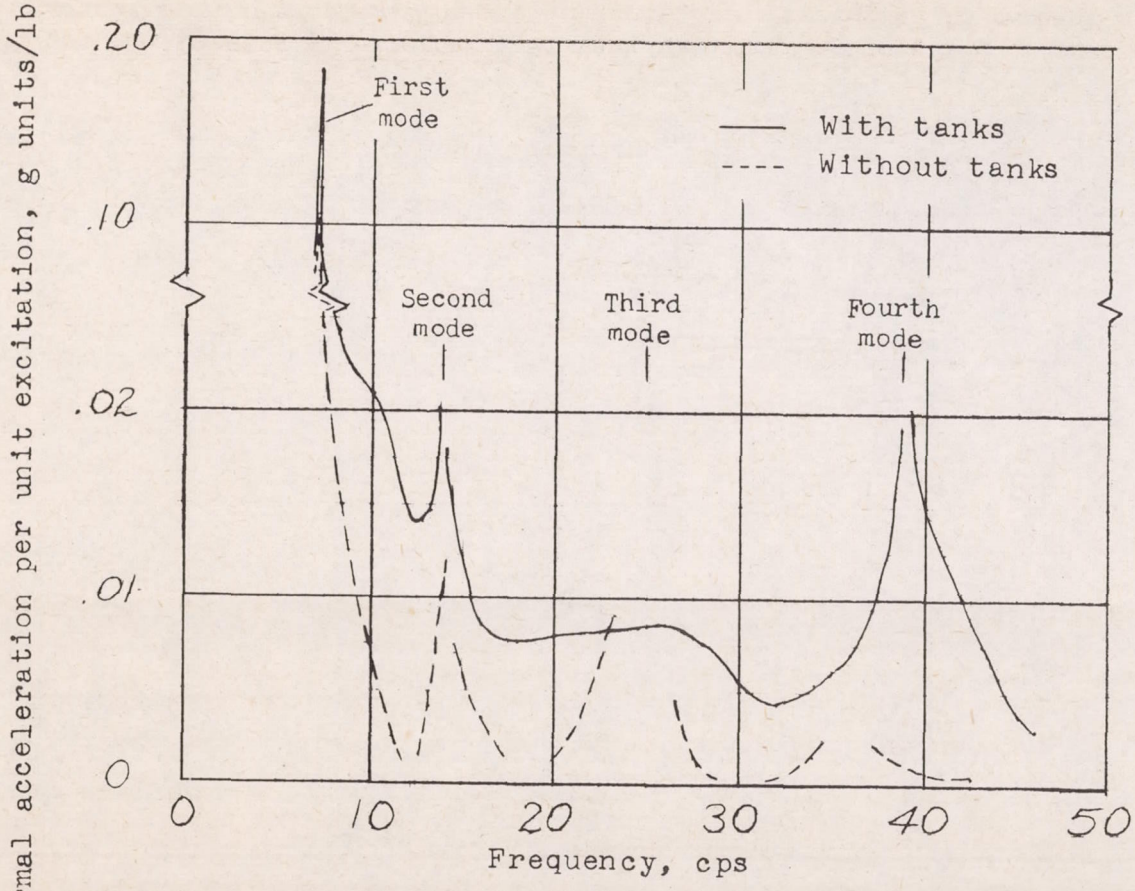
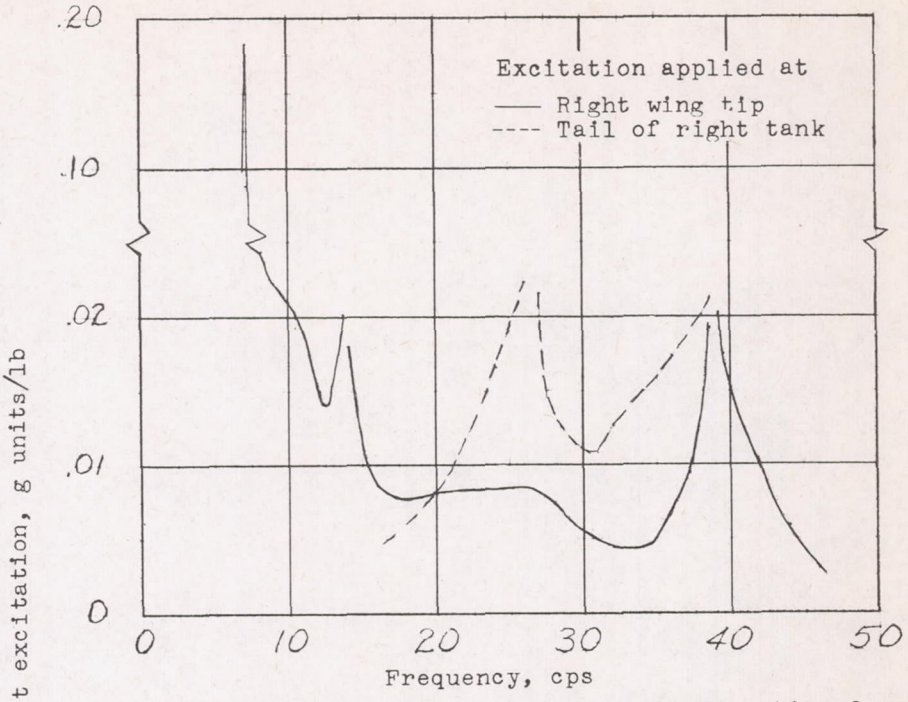


Figure 4.- Drawing of external fuel tank illustrating location of pressure measurement stations. The station locations (expressed in percent of total tank length measured from nose) and normal area represented by each station are given.

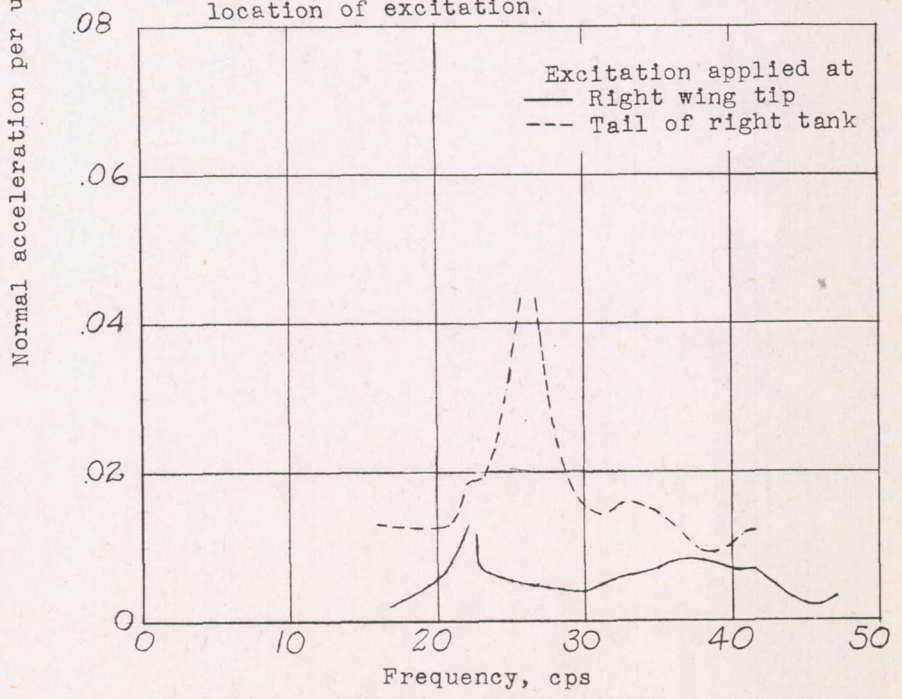


(a) Effect of tanks on response at the right wing tip, excitation applied at right wing tip. Note break in ordinate scale.

Figure 5.- Variation with frequency of the response of the airplane structure to sinusoidal excitation as measured during ground shaking tests.

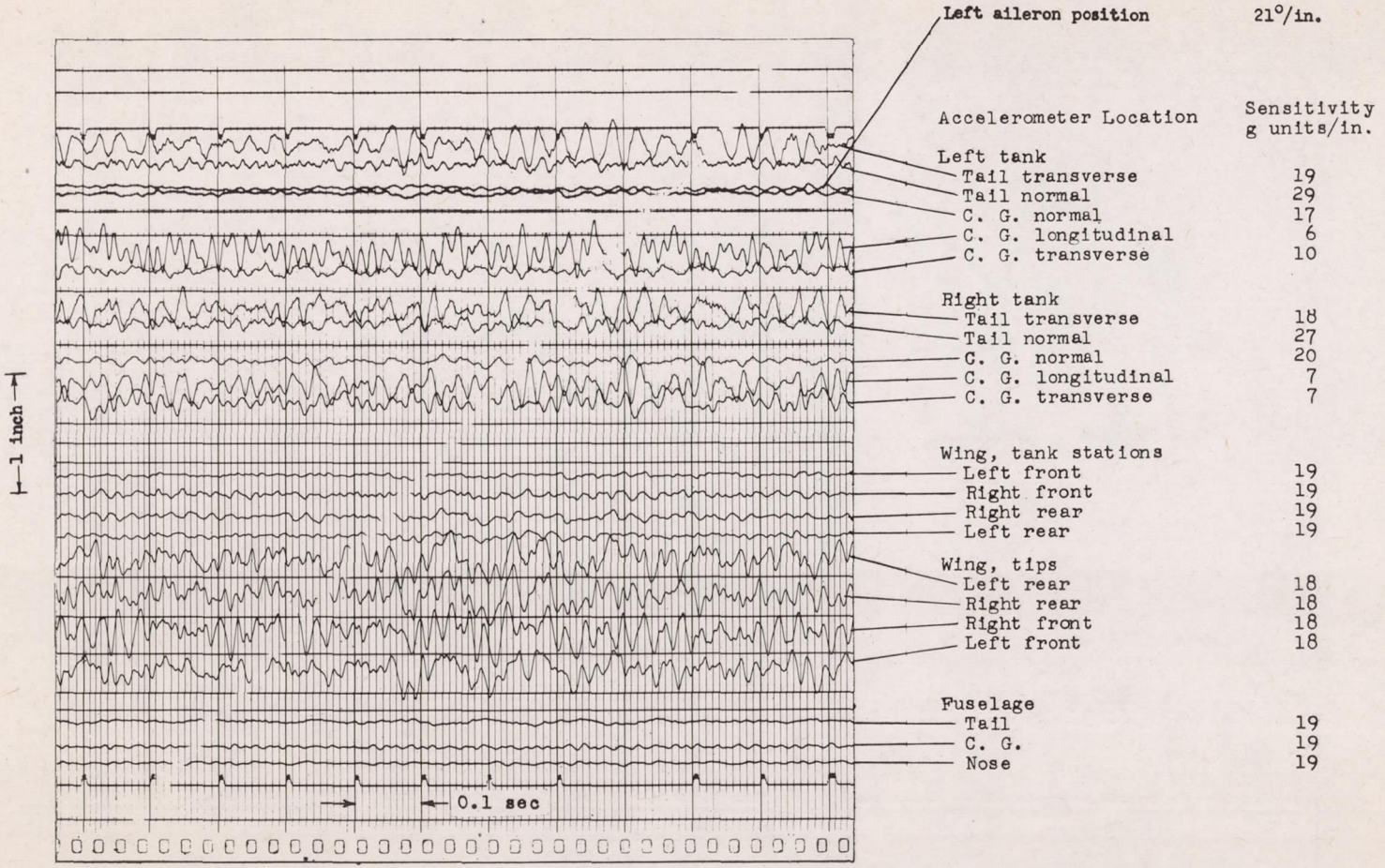


(b) Effect on response at the right wing tip of location of excitation.



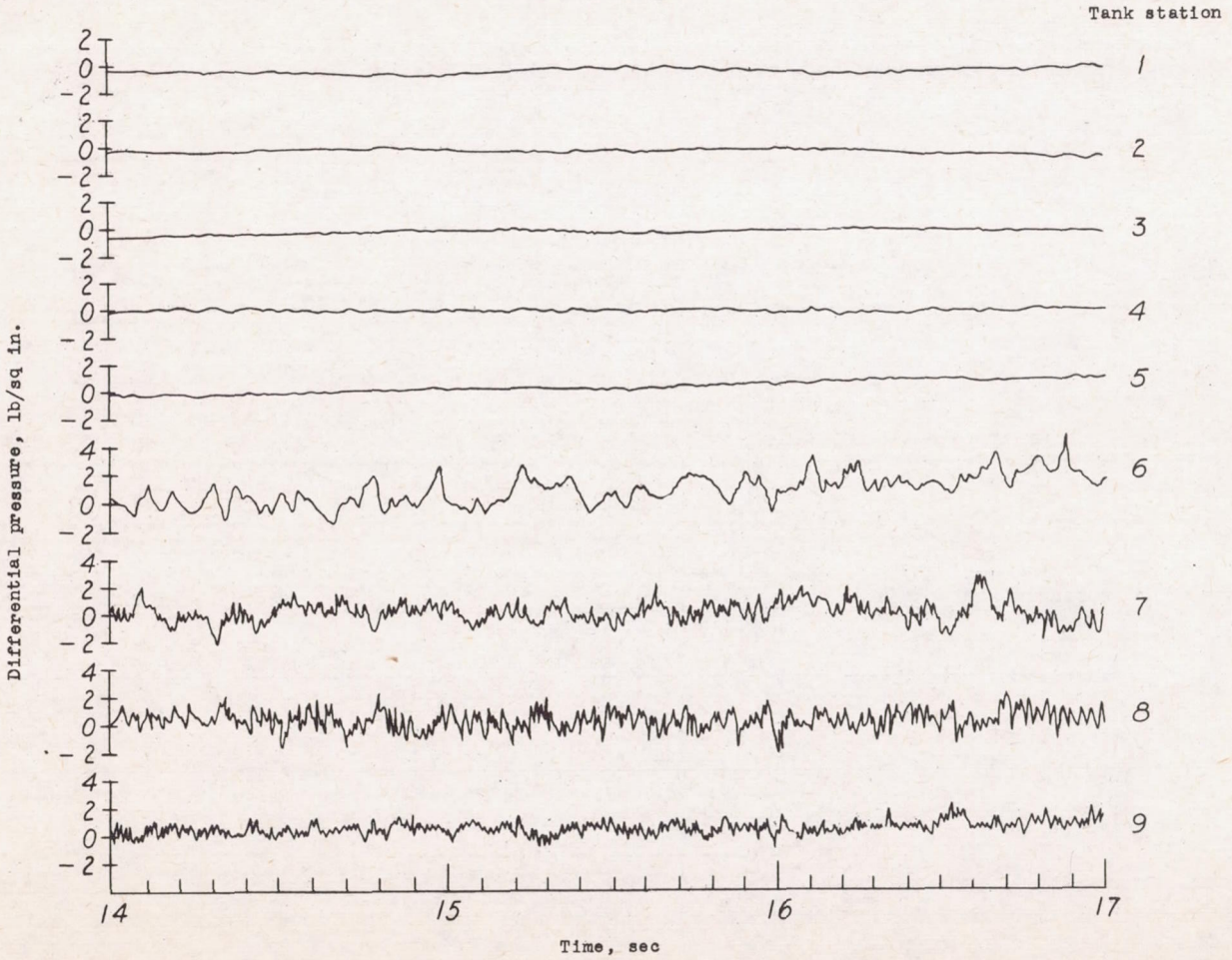
(c) Effect on response at the tail of the right tank of location of excitation.

Figure 5.- Concluded.



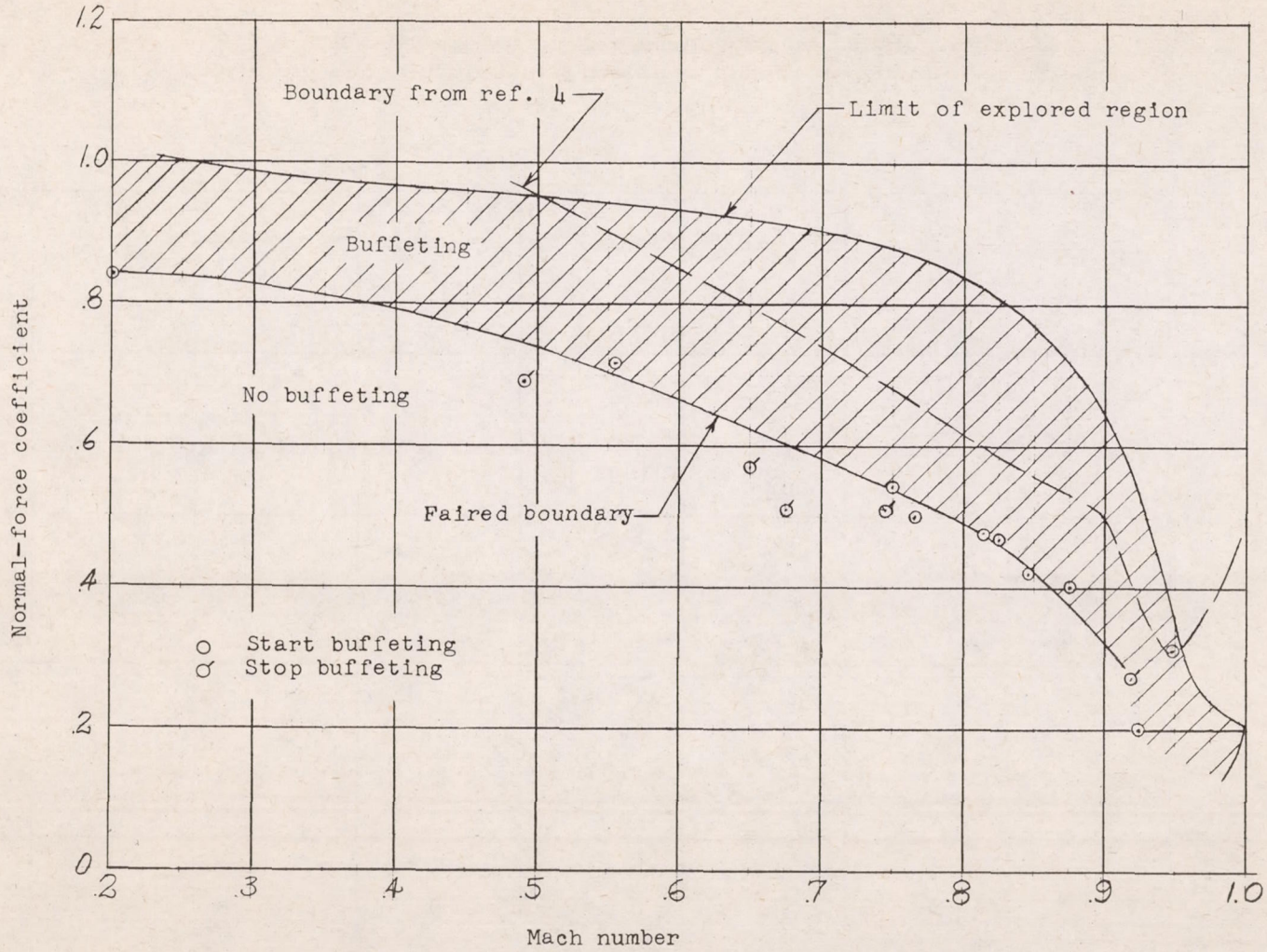
(a) Acceleration record. Upward deflection of traces corresponds to increased acceleration upward, to the right, or to the rear. Aileron position trace is also shown.

Figure 6.- Typical records obtained during buffeting at Mach number of 0.86, airplane normal-force coefficient of 0.14, and 24,000 feet pressure altitude.



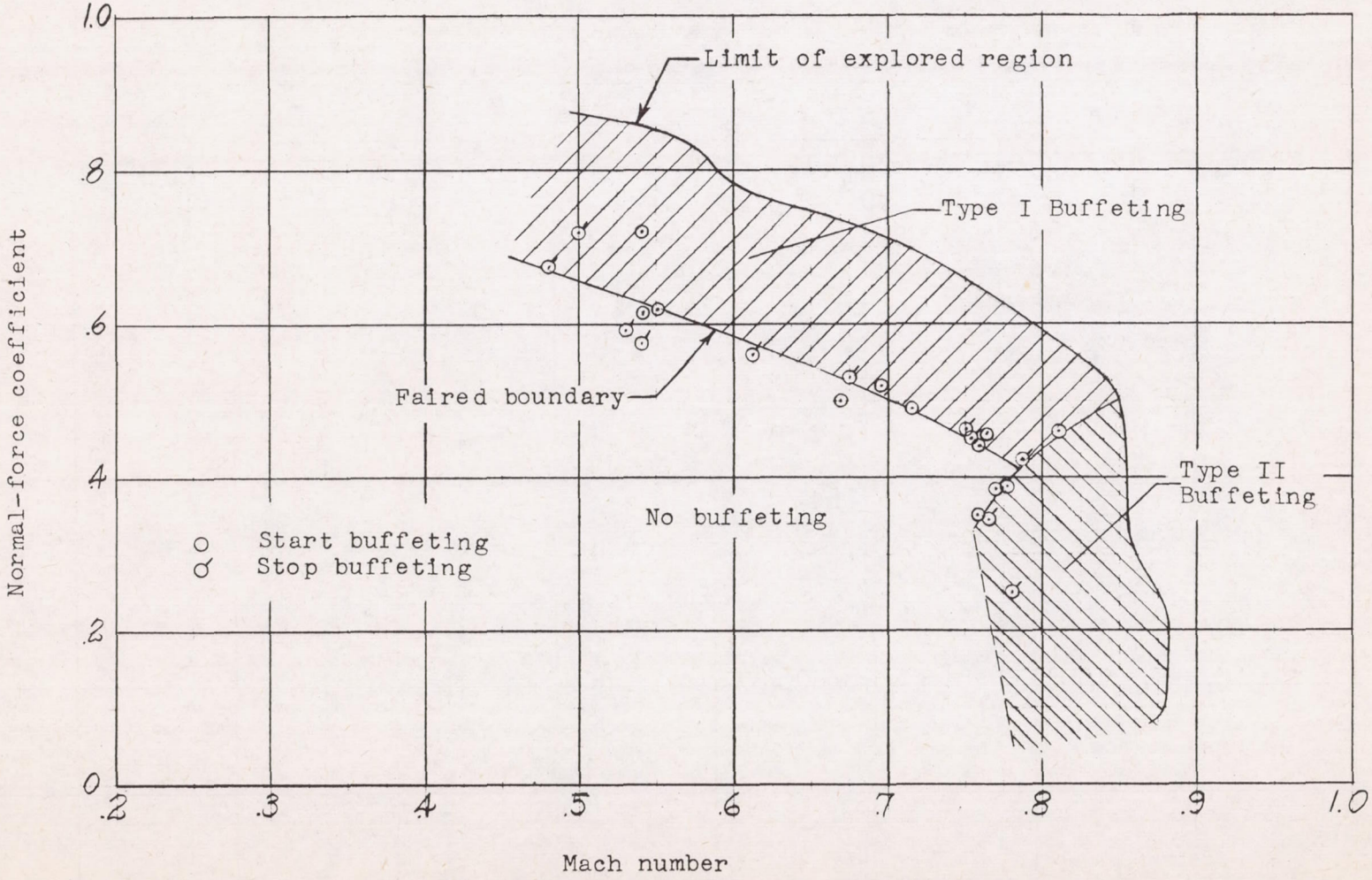
(b) Tracing of part of pressure record. Upward deflection of traces corresponds to increased upload on tank.

Figure 6.- Concluded.



(a) Airplane without tanks.

Figure 7.- Buffet boundary data.



(b) Airplane with external fuel tanks installed.

Figure 7.- Concluded.

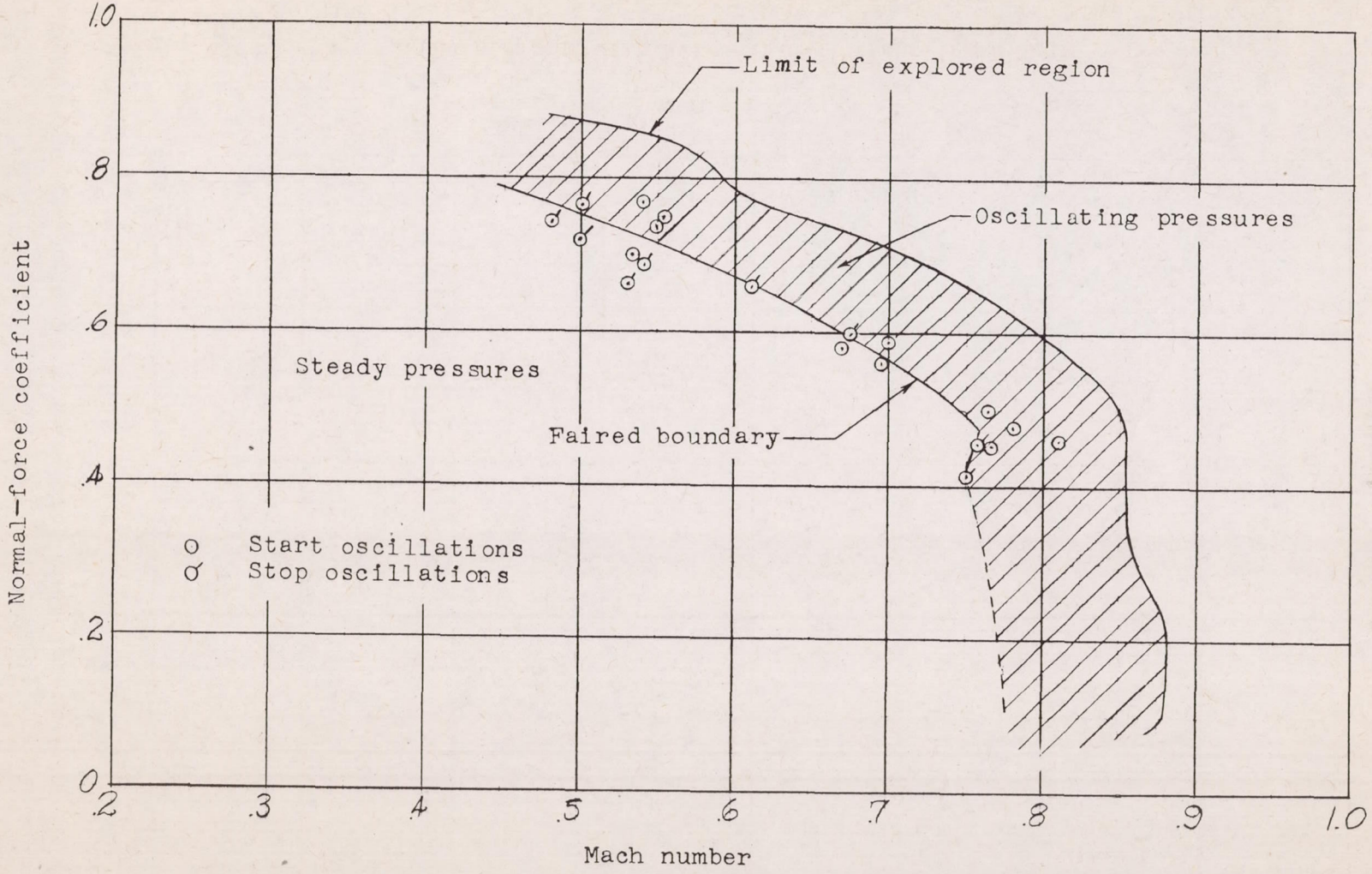


Figure 8.- Boundary data for occurrence of oscillating pressures on tank.

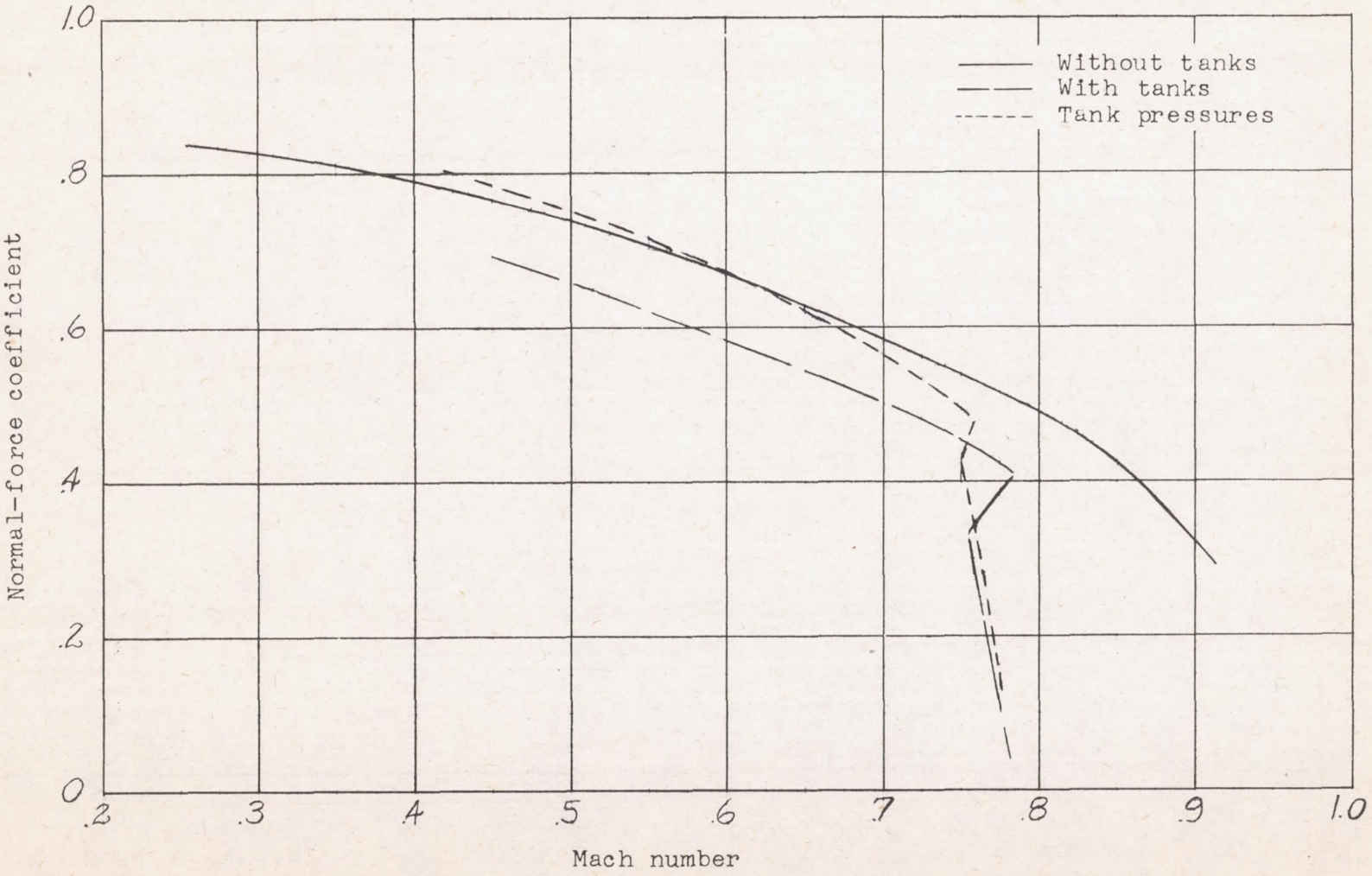


Figure 9.- Comparison of buffet boundaries for airplane with and without tanks with boundary for occurrence of oscillating pressures on tank.

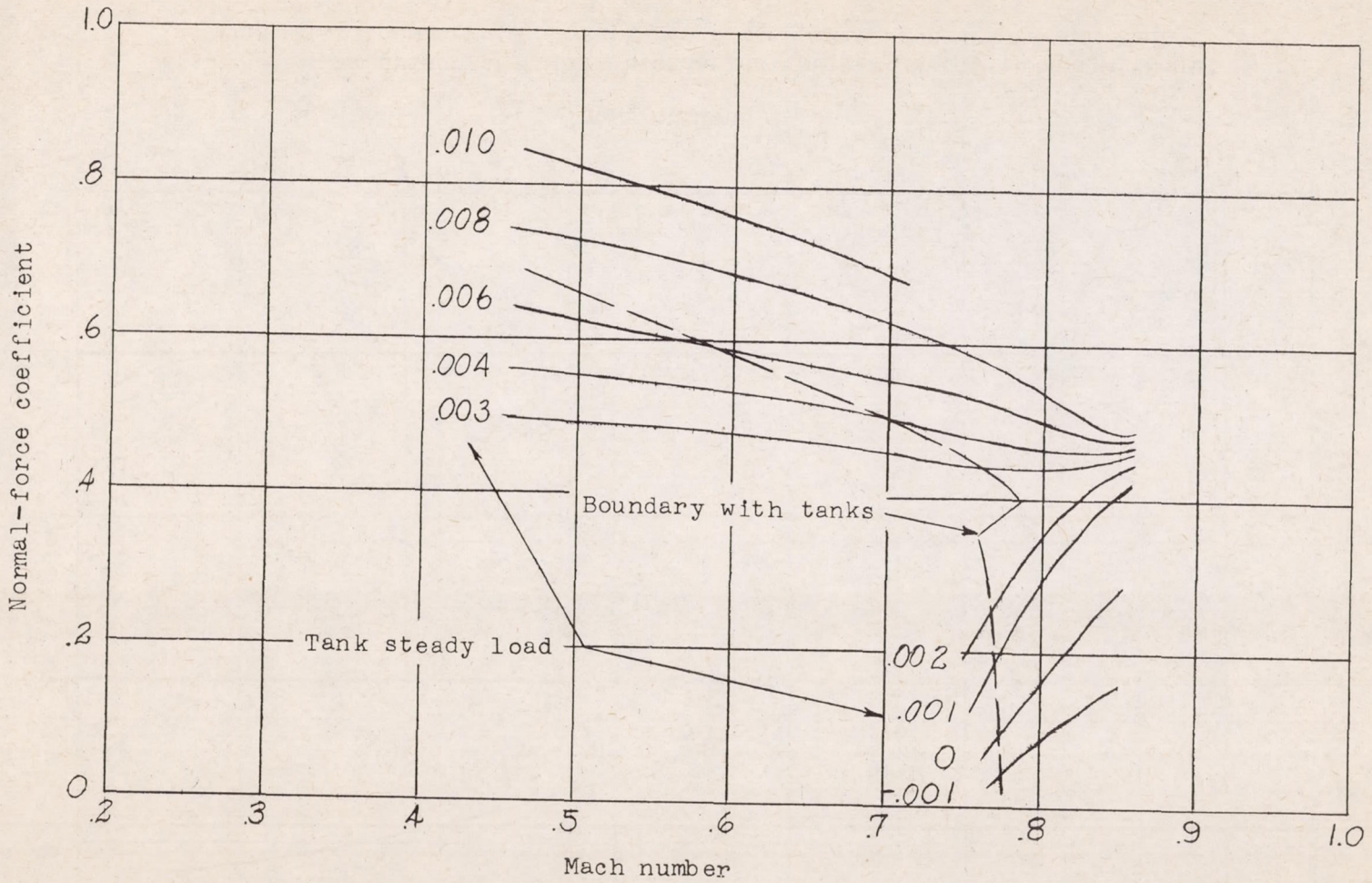


Figure 10.- Comparison of buffet boundary of airplane with tank installed with contours of constant tank steady normal load coefficient. The tank steady load coefficients are based on the airplane wing area and were plotted from data given in reference 2.

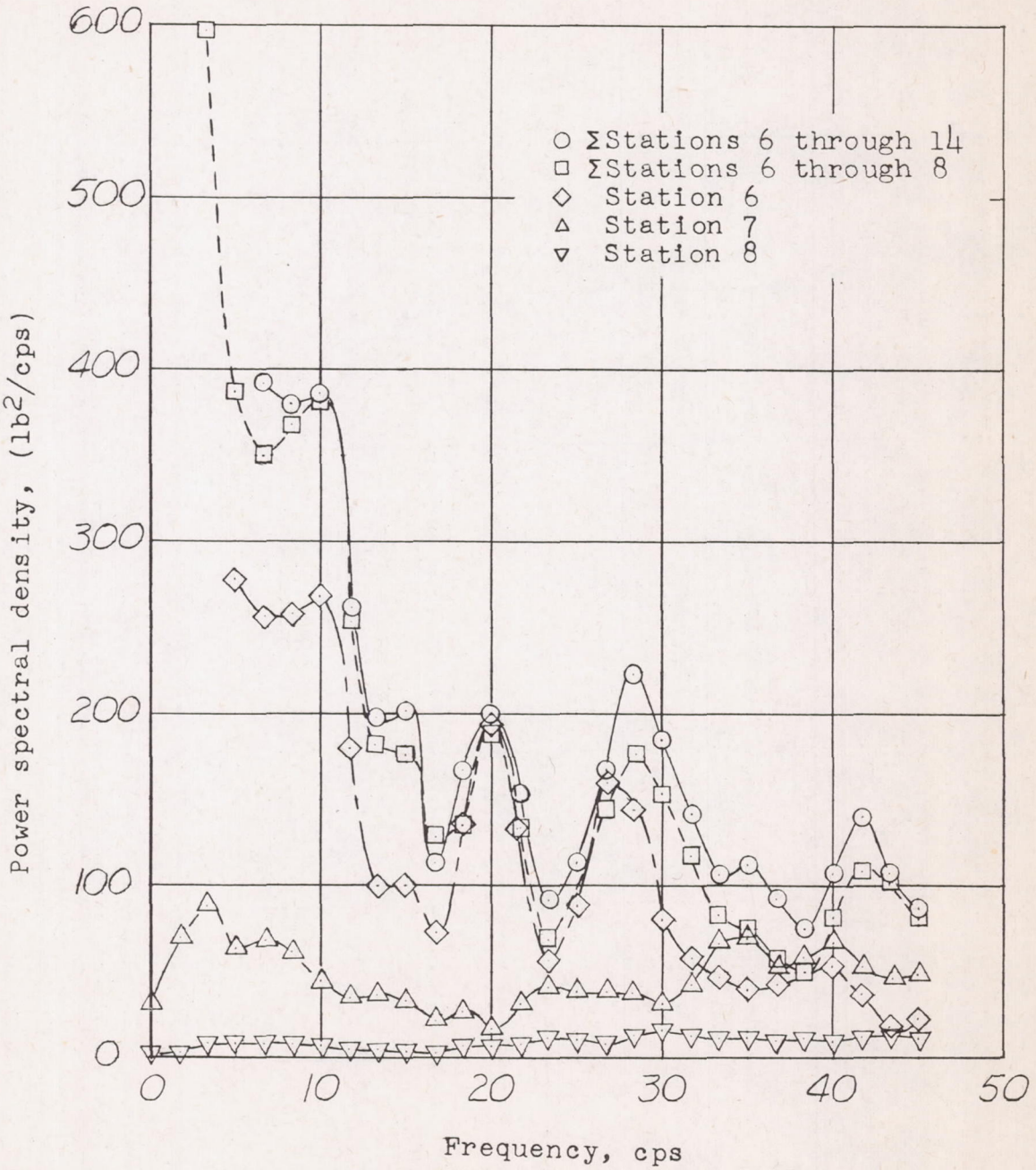
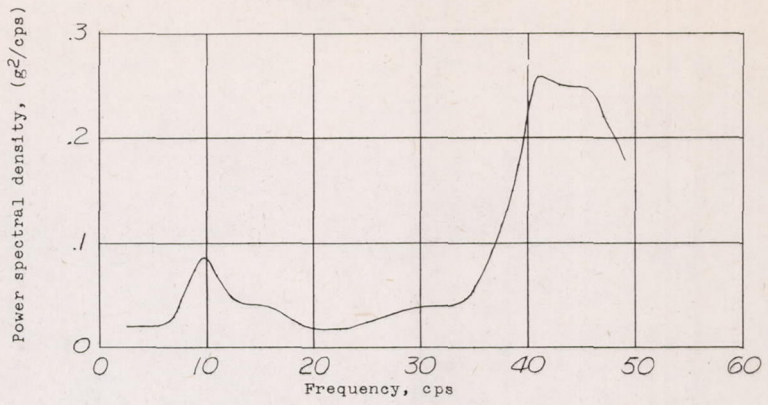
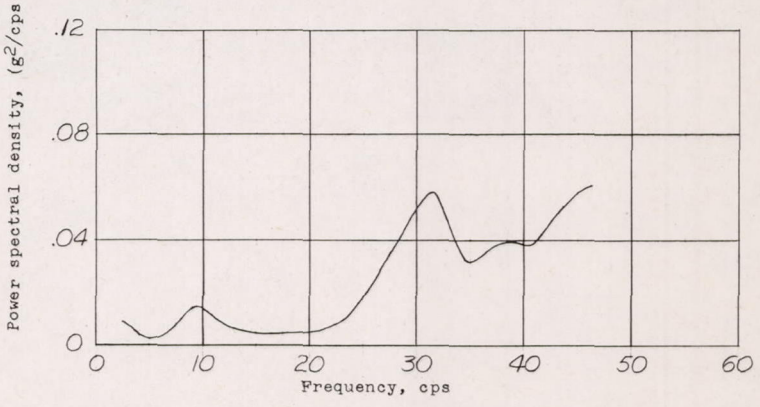


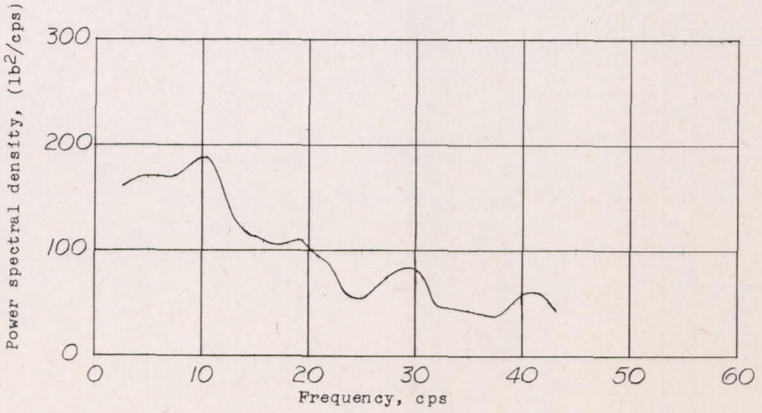
Figure 11.- Spectra of tank normal load for several combinations of the data computed by numerical techniques. Time interval 14 to 17 seconds.



(a) Acceleration at right wing tip.

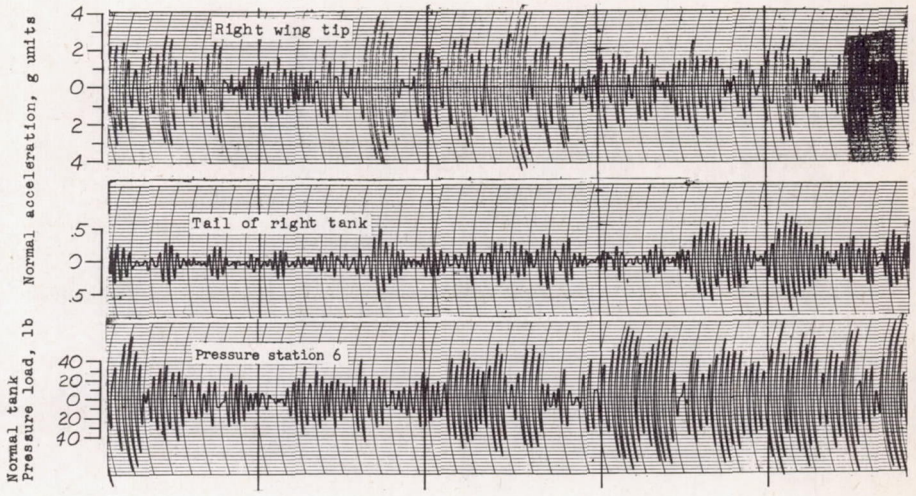


(b) Acceleration at tail of right tank.

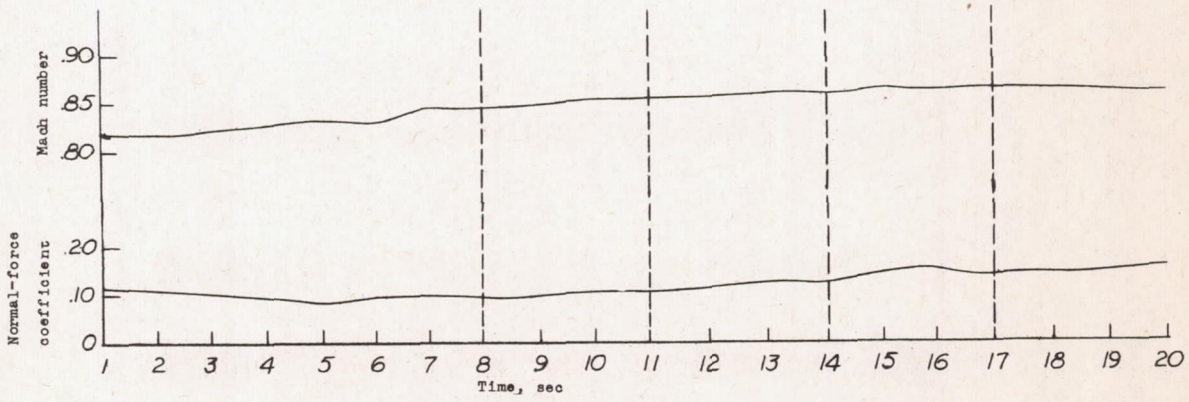


(c) Oscillating pressure load on tail of right tank (station 6).

Figure 12.- Spectra of accelerations and tank pressure loads obtained by electrical methods. Time interval 5 to 20 seconds.

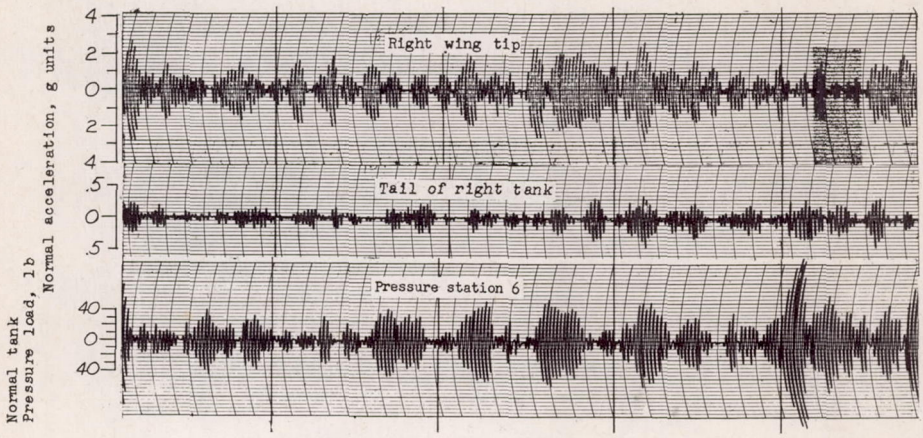


(a) 9 cps.

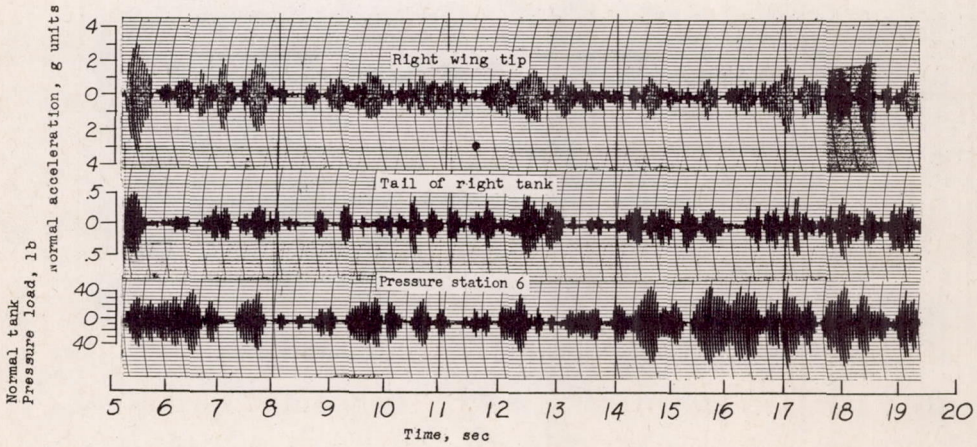


(b) Airplane normal-force coefficient and Mach number.

Figure 13.- Time histories of the principal components of accelerations and pressure load and of flight conditions during selected run.

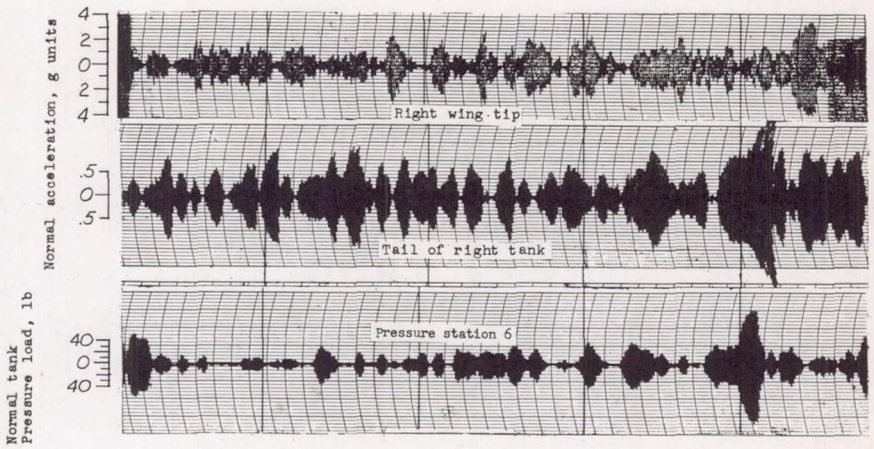


(c) 16 cps.

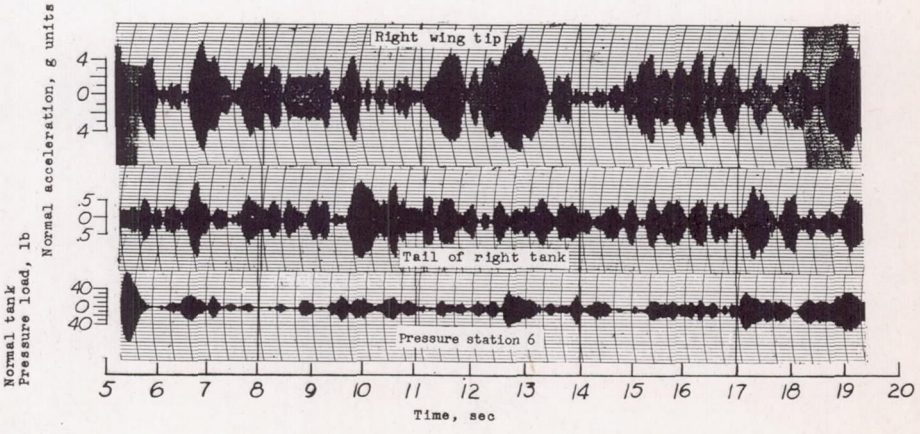


(d) 21 cps.

Figure 13.- Continued.

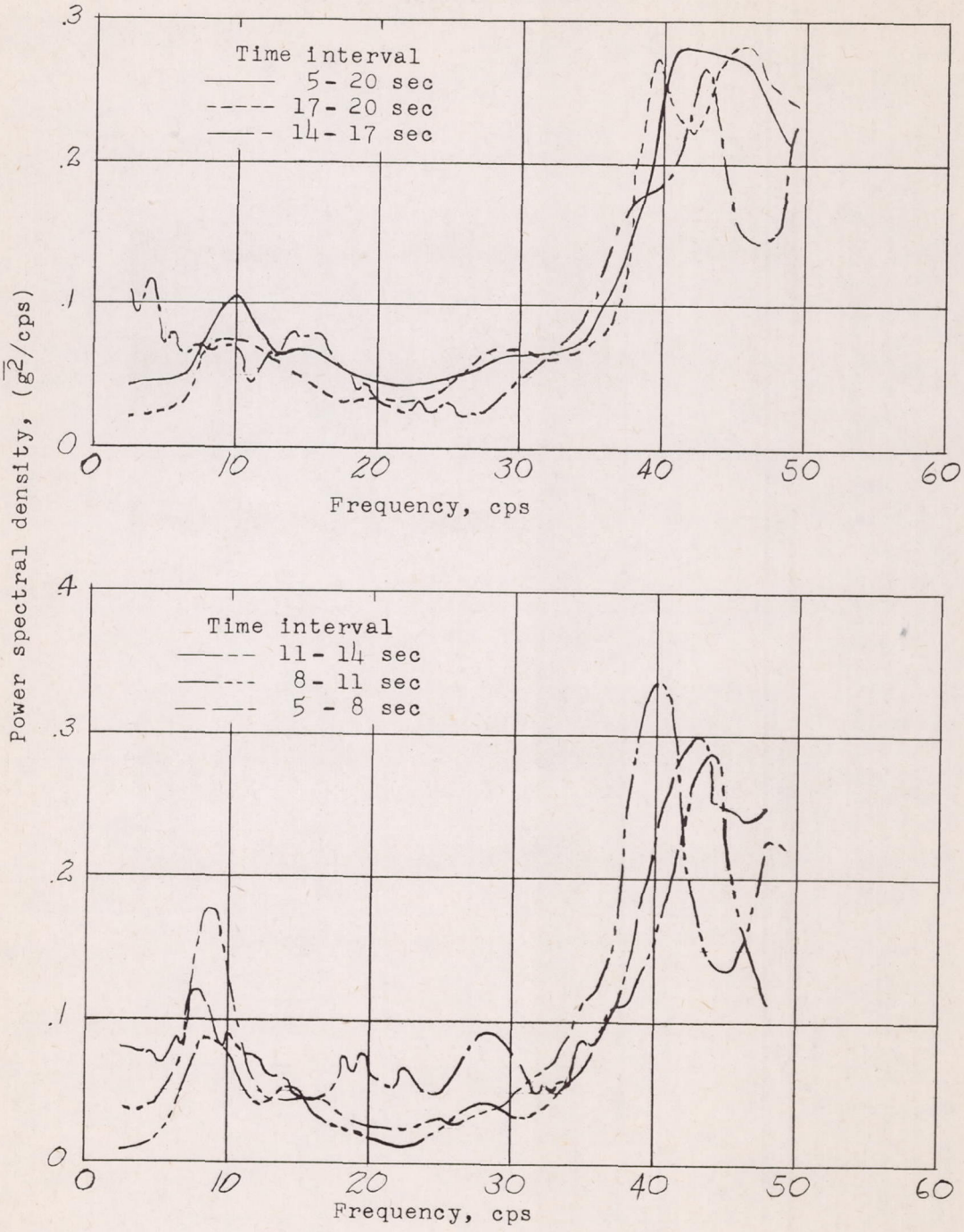


(e) 30 cps.



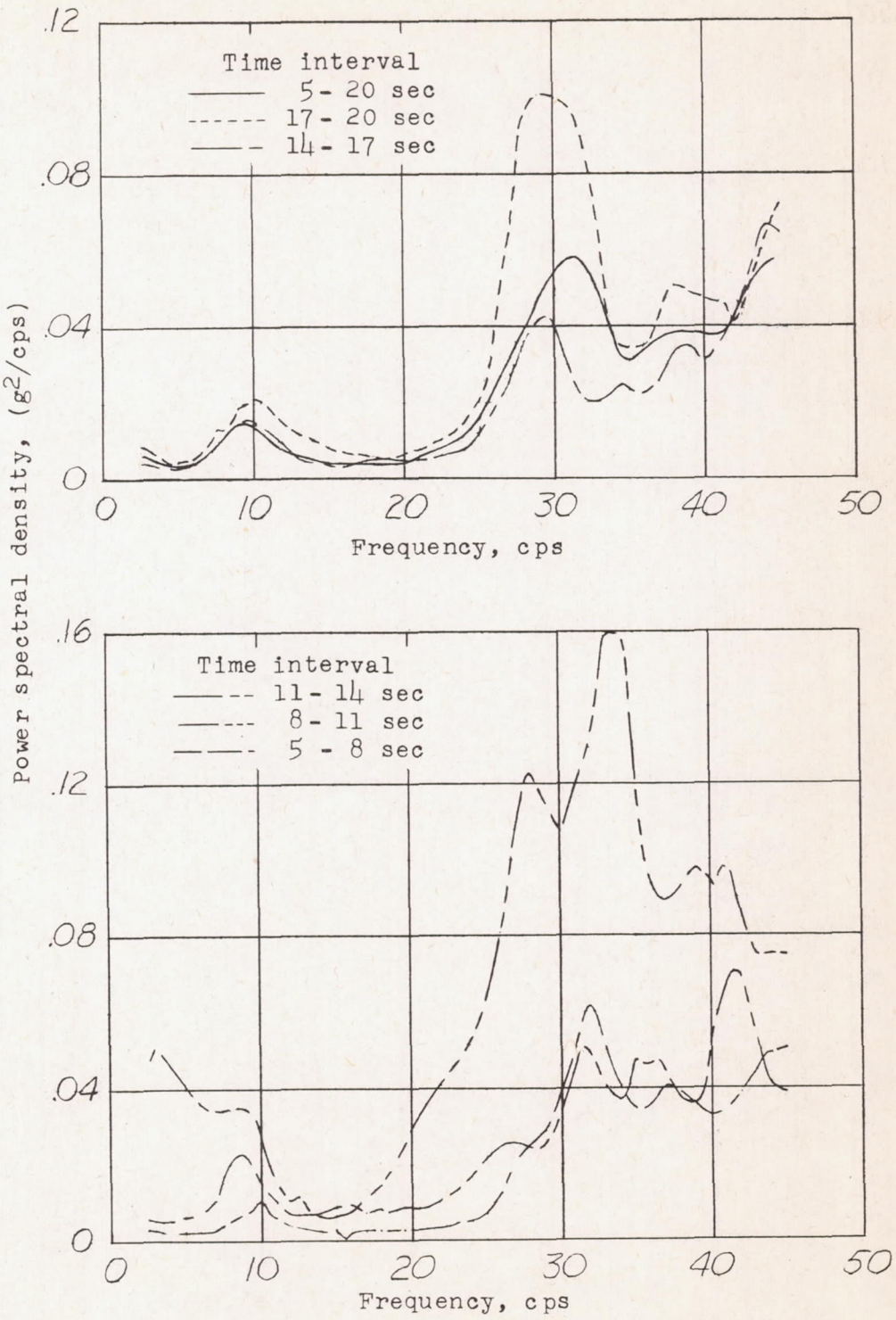
(f) 38 cps.

Figure 13.- Concluded.



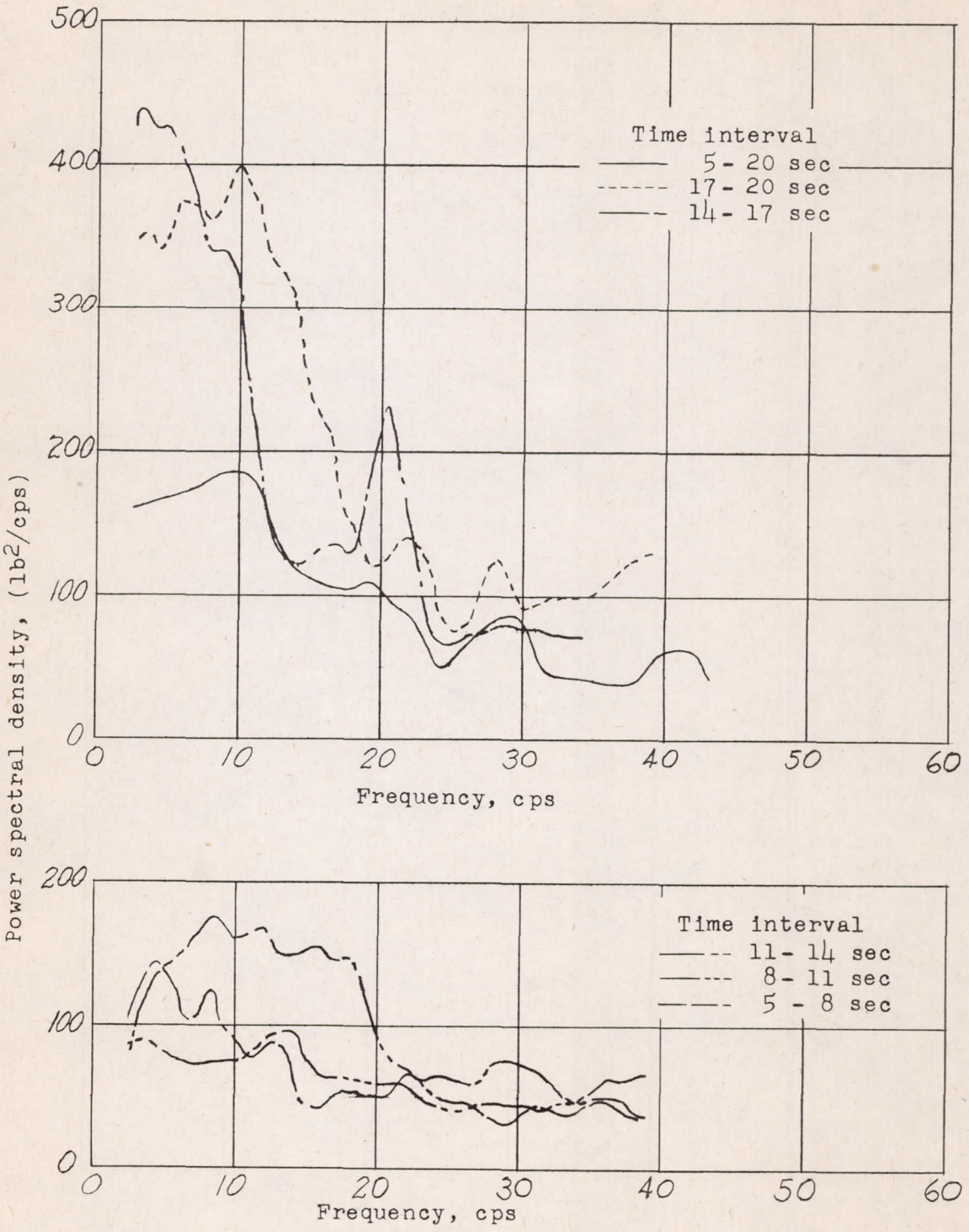
(a) Acceleration at right wing tip.

Figure 14.- Spectra of accelerations and tank pressure loads obtained by electrical methods for five consecutive 3-second intervals. Spectra for entire 15-second interval (taken from fig. 13) are included for comparison.



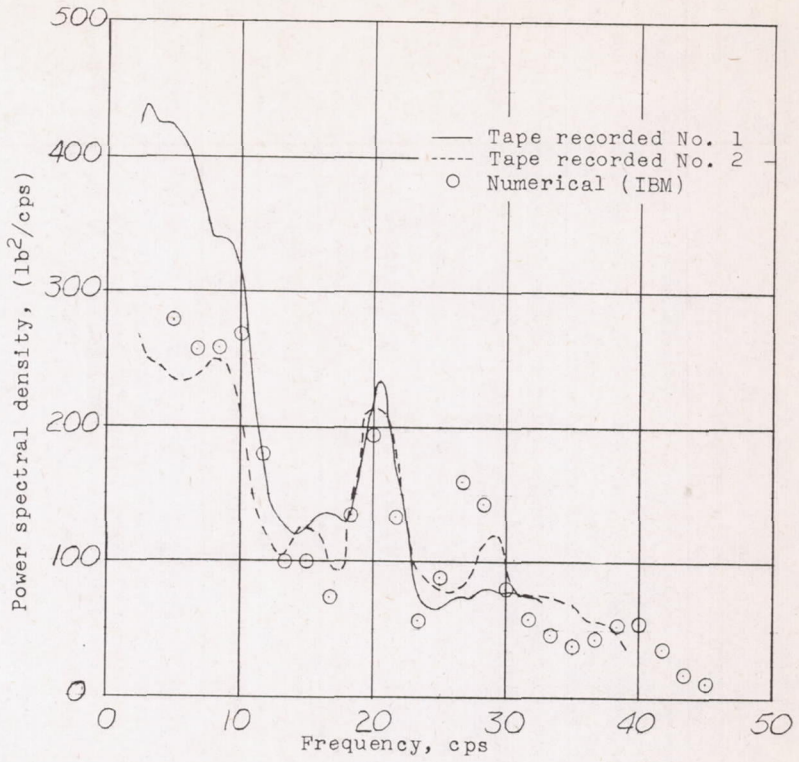
(b) Acceleration at tail of right tank.

Figure 14.- Continued.

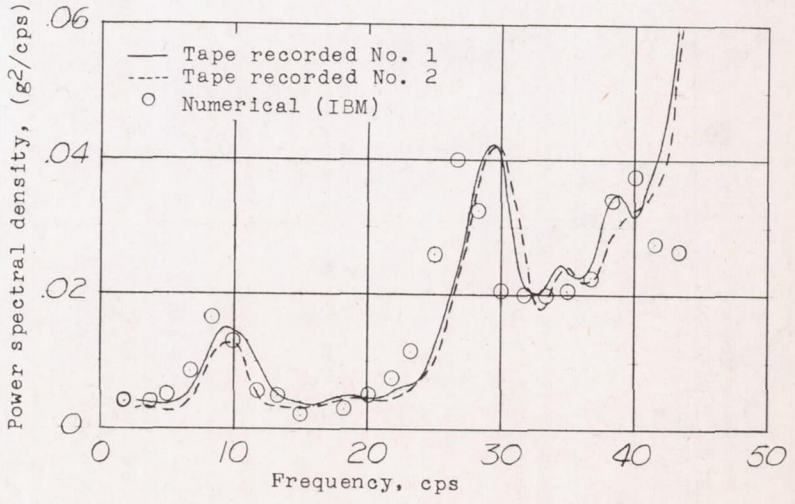


(c) Oscillating pressure load on tail of right tank (station 6).

Figure 14.- Concluded.



(a) Oscillating pressure load on tail of right tank (station 6).



(b) Acceleration at tail of right tank.

Figure 15.- Two examples of comparison of spectra obtained from the same basic data by numerical techniques (IBM) and by electrical methods. Two independent samples of the results of electrical methods are given for each case.